Science & Technology Foresight Center of NISTEP

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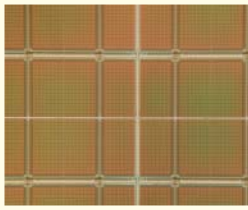

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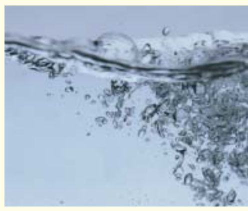

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Foreword

This is the latest issue of "Science and Technology Trends — Quarterly Review".

National Institute of Science and Technology Policy (NISTEP) established Science and Technology Foresight Center (STFC) in January 2001 to deepen analysis with inputting state-of-the-art science and technology trends. The mission of the center is to support national science and technology policy by providing policy makers with timely and comprehensive knowledge of important science and technology in Japan and in the world.

STFC has conducted regular surveys with support of around 3000 experts in the industrial, academic and public sectors who provide us with their information and opinions through STFC's expert network system. STFC has been publishing "Science and Technology Trends" (Japanese version) every month since April 2001. The first part of this monthly report introduces the latest topics in life science, ICT, environment, nanotechnology, materials science etc. that are collected through the expert network. The second part carries insight analysis by STFC researchers, which covers not only technological trends in specific areas but also other issues including government R&D budget and foreign countries' S&T policy. STFC also conducts foresight surveys such as periodical Delphi surveys.

This quarterly review is the English version of insight analysis derived from recent three issues of "Science and Technology Trends" written in Japanese, and will be published every three month in principle. You can also see them on the NISTEP website.

We hope this could be useful to you and appreciate your comments and advices.

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Executive Summary

Life Sciences

1 Recent Trend of Immunology

p.11

The immune system is a biophylactic tool that is essential for human beings. Immunology has to date clarified many basic concepts including individual cells and molecules involved in the immune response as well as their functions, and relationship between the immune system and diseases. The development of vaccines and immunosuppressants has made great contributions to the prevention of infections and the realization of transplantation therapy.

However, there are many problems that remain unsolved including control of refractory infections such as AIDS and development of vaccines, clarification of the development of allergic diseases and immunological intractable diseases that are increasing in advanced countries, and development of preventive methods and therapies. There are high expectations on regenerative medicine and gene therapy as state-of-the art therapies, but in order to put them into practical use, the significant problem of rejection of the immune system remains to be solved.

It is expected that immunology in the future will systemically tackle these problems to meet these clinical needs. For example, the following subjects are demanded: to attempt efficient research and development by means of project-type researches; to utilize a foothold of researches such as RIKEN Research Center for Allergy and Immunology; to develop common base technology such as database build up specifically for immunity; and to arrange a system of translational researches that apply the results of exploratory basic researches to clinical studies.

There are many phenomena that remain to be solved in the immune system, and, after this, it is necessary to accumulate basic knowledge and findings further in order to comprehensively understand the entire picture of the complicated immune system. To realize this, it is necessary to attempt to enrich research aid such as the Grant-in-Aid for Scientific Research, which gives a large degree of freedom to individual researchers, and to promote personal-idea-type researches based on personal intellectual curiosity or original ideas. At that time, it will also be required to improve the evaluation system, for example, attempting to conduct open evaluations.

(Original Japanese version: published in July 2002)

2 Present and Future of Bioresources (Biological Genetic Resources)

p.19

Bioresources are inevitable for conducting research in the life science area. Since bioresources include diverse materials, such as various experimental animals and plants, model animals and plants, embryos, cells, tissues and organs, they must be collected, stored and supplied on a national basis. Currently, studies for analyzing gene functions dominate the research in the life science area, and strategic organization of resources linked with genome research is required.

In order to promote smooth utilization of bioresources, the establishment of institutions for storing and supplying bioresources (resource centers) is important, as well as for systems such as contracts for ensuring smooth transfer of materials.

In recent years, many related policies have been implemented, including the establishment of resource centers. Since the values of bioresources are unstable and education of human resources specialized in bioresource management requires policies on a long-term basis, such policies require follow-ups in the future.

(1) In the life science area, the main research subject has changed from phenomenon to phenomenon along with time, so the values of the bioresources have also changed. Therefore, support policies with time limits are urgently required for materials such as mutants and transgenic organisms that are artificially produced in large amounts. Meanwhile, for irreplaceable resources such as natural subspecies and related species, it is important to develop inexpensive, resource-storing techniques while promoting permanent collection and management of the resources. Therefore, a good balance between short- and long-term support policies is required.

(2) Since bioresources show uniqueness in their maintenance and propagation techniques for individual species, it is important to educate specialists for maintaining and managing bioresources with high added values. Short-term financial support for resource organization is insufficient for establishing superior technician promotion systems as in the U.S. and Europe. Therefore, mid- to long-term support policies are necessary for ensuring a sufficient level of human resources.

(3) Assuming that gene functions will be analyzed in various species in the future, genomic data will become closely linked with the information on the traits at an individual level. Therefore, information on bioresources accompanying genome information should become more and more important. As a conclusion, for databases of genomic data such as the sequence data, it is important to contemplate the construction of a well-disciplined description method for bioresource information.

(Original Japanese version: published in September 2002)

Information and Communication Technologies

3 Research Trend in LSI Technologies
— Report on Presentations at the VLSI Symposia and the Silicon Nano-electronics Workshop —

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The annual "VLSI Symposia" (consisting of the "Technology Symposium," concerning device technologies, and the "Circuit Symposium," concerning circuit technologies) and the "Silicon Nano-electronics Workshop," both of which are among major international conferences on LSI technologies, were held in Hawaii, US, in mid-June this year. There were presentations on semiconductor technologies including future technologies for the 130nm generation and the 65nm and later generations.

In the Technology Symposium, there were vigorous presentations on the high-dielectric constant gate insulation film (measures to cope with the problem of the thinned gate insulation film and increased gate leakage current as a result of miniaturization). In the Circuit Symposium, there were heated debates on system on chips and low power consumption technologies, which are becoming increasingly important as high integration advances. However, it appears that a decisive solution for low power consumption technologies has not been developed. At the Nano-electronic Workshop, FinFET was proposed as a new transistor structure.

FinFET is a 3D structure that is expected to achieve greater speed and lower power consumption than conventional planar transistors. A prototype device was developed, and it was established that the new structure has superb properties.

For lithography for the 65nm generation, the F_2 lithography has been the leading candidate on the roadmap. Recently, however, EUV and EPL are taking over the F_2 technology due to its technical difficulty and time for commercialization. Additionally, prolonging the life of ArF to the 65nm generation is being studied, and a presentation on resolution-enhancing technology that allows this attracted attention.

For the 65nm and later generations, individual technologies are steadily progressing, and those technologies that will play major roles are being determined. However, it seems that a favorite has yet to be determined.

In addition, concerning the numbers of papers by country, it is notable that the presence of South Korea and Taiwan are growing.

(Original Japanese version: published in July 2002)

4 Trends in Grid Technology

— Will the Grid technology became the core technology for the next-generation Internet application? —

p.34

The Grid technology enables to create environments in which a network of multiple high-performance computers can be used as a single virtual computer. In such environments, participating researchers can share large-scale computer systems and expensive specialized laboratory equipment. The Grid is expected to become an essential research infrastructure for big science such as high-energy physics and space science and in cross-disciplinary research fields created by the convergence of information technology and biotechnology/nanotechnology. In addition, distribution of computer resources enables peak load sharing and improved reliability, leading to discussions on the possibility of commercialization of Grid technology.

There are various types of Grids: (a) Metacomputing allows large-scale computations by using multiple high-performance computers distributed across the network; (b) Research Grids (Virtual Laboratories) enable the members of a research community to share computer resources, data, and laboratory equipment; (c) Data Grids provide environments in which large-scale data sets distributed across the network can be shared; (d) Computing Service Grids offer computation services by using a virtual computer created on the Grid; and (e) Desktop Girds enable supercomputer-level computations by gathering the untapped computing power of a large number of idle PCs over the Internet.

To make these schemes a reality, massive-scale Grid construction projects are in progress worldwide. Leading-edge activities include the TeraGrid project in the U.S. and the EU Data Grid in Europe. Application fields of the Grid have extended to high-energy physics, genomics, biotechnology, protein structure analysis, medicine and health care, environment, meteorology, astronomy, chemistry and materials.

Fortunately, Japan has leading research expertise in Grid technology, together with domestic computer manufacturers. To secure Japan's technological presence in next-generation Internet application technologies, universities, national laboratories and computer makers should collaborate for the creation of prominent technologies and contribution to the standardization of the Grid.

(Original Japanese version: published in September 2002)

Environmental Sciences

5 Trends in the Studies of Heat Island Mitigation Technology

— Analysis from the Viewpoint of Energy Use —

p.48

The heat island phenomenon, which is becoming a major problem not only in megalopolises but also in local cities, is a typical environmental concern related to urban energy use.

A number of models have been developed to analyze the heat island phenomenon; the results of various simulations indicate that measures such as the promotion of greening are effective in mitigating this problem. Based on architectural engineering and other expertise, moreover, a variety of technologies have been developed to shield buildings from the heat of solar radiation. Other mitigation technologies including water-retentive paving materials are also being examined from the viewpoint of town improvement.

In consideration of the energy supply in the future, distributed power sources — i.e., cogeneration systems such as fuel cells and gas turbines — are expected to become widespread. From the perspective of energy, this means that heat energy currently being discharged into the water by thermal plants and other power facilities located in suburbs will be brought into the city — a situation that would further promote the heat island phenomenon.

In order to assess this problem in a quantitative manner, studies are underway for simulating the amount of waste heat. In the case of a model based on decentralized power sources using natural gas, the amount of waste heat will increase compared to the business-as-usual model if their power generation efficiency and heat utilization factor remain at low levels. Accordingly, temperatures will increase in the city. If these two indexes are comparatively high, the amount of waste heat will be equal to that expected for the business-as-usual model.

Effective ways to mitigate the heat island phenomenon are thus to devise and promote realistic measures for buildings, while developing distributed power sources, power generation efficiency and heat utilization factor of which can be maintained at high levels.

(Original Japanese version: published in August 2002)

Nanotechnology and Materials

6 Trends in Research and Development of Fine-Grained Metallic Materials

— Aiming at the Next-Generation High Strength Materials —

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In view of energy saving, resource conservation, and global environment protection, lighter, stronger, and recyclable materials are being sought for. According to one estimate, for example, improvement in fuel consumption resulting from lighter vehicles will reduce the total emission of CO_2 in Japan by 2 -

3%.

It has been confirmed by recent basic studies that properties of metals such as strength, toughness, and corrosion resistance are significantly improved by refining the grain size. In Japan, aiming to double the strength of metals, national projects such as Ultra-Steel Project and Super Metal Technology Project are being conducted to develop the technology that reduces the grain size down to 1 μm or less in steels of simple composition that have normally a grain size of 10 - 15 μm by heavy deformation. Such steel is easily recycled because no special alloying elements are added. The projects are now in the second stage, and more emphasis is going to be placed on the development of practical application.

Apart from the national projects, Nakayama Steel Works, Ltd. announced November 2001 that they had succeeded in developing hot rolled fine grain plates (NFG) by their original technology. This product has a grain size of 2 - 5 μm and a strength of 1.5 - 1.6 times that of conventional steels, and they started production and sales of the fine-grained steel for the first time in the world. NFG is the object of public attention because it will tell the future of the practical application of fine-grained steels.

Japan is now running ahead of other countries in the development of fine-grained steel. In order that Japanese steel industry and other metal industry may maintain the international competitiveness, it is essential to differentiate their products by adding extra values, and this requires the development and commercialization of high functional materials with close cooperation among the academic, business, and governmental circles. In this sense, much is expected from the above-mentioned national projects.

(Original Japanese version: published in July 2002)

7 Trend of Self-Organization in Materials Research

p.67

The self-organization process, in which "desired materials and devices are fabricated, without subjecting their constituents to artificial processes, through the self-organization of their constituents or through the self-assembly of their constituents to form specific patterns in dynamic state where energy and substances dissipate," has attracted attention because the process is expected to realize the fabrication of nanostructures in a resource-saving and energy-efficient manner.

The goals in self-organized material research may include the following three: (A) Precision synthesis of molecular clusters; (B) Establishment of technologies of patterning and self-aligning; and (C) Production of materials and devices through the self-organization mechanism. In order to handle technical challenges to be tackled to achieve these goals, a wide variety of innovative research has been conducted in Japan. As a result, great achievements have been accomplished, including the synthesis of materials with a three-dimensionally closed structure having unique inner space on nanometer scale inside their molecular skeletons, which are extremely difficult to produce by conventional chemical synthesis. So far, Japan leads the rest of the world when it comes to material fabrication technologies by the self-organization mechanism.

In order to achieve a breakthrough or to realize smooth application of the findings obtained in basic research to industrial production of nanomaterials or devices using such materials, it is necessary for researchers in various fields or organizations to share the sense of mission in research activities and to pursue research in an interdisciplinary and comprehensive manner. To meet this need, we should "aim to give a concrete image to everyone of the 'fabrication of a computer in a beaker,' and gather researchers in various fields of expertise who are interested in, or recognize the significance of, the achievement of this objective" and should "secure and develop human resources to serve as an interface between such theoreticians and experimentalists."

(Original Japanese version: published in July 2002)

Manufacturing Technology

8 New Development in MEMS Research

p.82

MEMSs (Micro Electro-Mechanical Systems) is defined as a micro mechanical system including the movable parts produced using the processing technology that has been accumulated through the development of semiconductor devices. Targets of research and development are not limited to mechanical parts but are expanding to a wide range of applications including medical, biological, and energy storage technologies. Products produced by MEMS technology are essentially based on a wide variety of small-lot, and the technology is expected to vitalize the industry including venture businesses.

Not only in the United States and European countries that are advanced in MEMS technology but also in Asian countries such as Taiwan and Singapore with the support of their governments, there is a strong trend to develop MEMS technology as one of new core technologies of industry. Since they are directing the MEMS technology as the parts supply industry, which has been the specialty of Japan, we cannot take a wait-and-see attitude. In future research and development of MEMS, it is necessary to create new systems by integrating microelectronics, nanoscience, and other technologies into micromachine and sensor technologies. It requires system engineering education that discusses "what" to make rather than "how" to do, and it is very important to foster human resources to handle the overall design including all of conceptualization, design, and prototyping. For Japanese universities and private foundries (manufacturing by contract), which are now being arranged to be utilized effectively for the vitalization of industry, it is necessary to make systematization.

(Original Japanese version: published in September 2002)

Others

9 The Status of Japan's Participation in Science and Technology Contests

p.95

International science and technology contests began in the 1950s, and have developed to include new fields such as informatics. In Japan, contests are held in fields such as mathematics, scientific research, technology, some with participants from overseas. The existence of such contests, however, is not widely known in Japan.

In this report we will therefore present an overview and the status of Japan's participation in science and technology contests including the Science Olympiads (mathematics, physics, chemistry, informatics, biology, astronomy), the International Science and Engineering Fair, the ACM International Collegiate Programming Contest, the Supercomputer Programming Contest, NHK Robocon, RoboCup, and the World Skills Competition. China, Russia, the United States, South Korea, and Taiwan are the top performers in recent Olympiads. Japan ranks in the second 10 in the Mathematical Olympiad, the only one in which it competes. Only a very few Japanese compete in the International Science and Engineering Fair. Japanese contestants rank in the mid-teens in the ACM International Collegiate Programming Contest. South Korea is overwhelmingly powerful in the Skills Olympics, while Japan usually ranks third or fourth.

Japan is not a top performer in such international contests. As various contests are held, however, phenomena such as elementary and junior high students who perform well alongside high school students and high school students who write computer programs superior to those of college students give cause to hope in future possibilities. Holding and participating in science and technology contests bears watching as one index of science and technology.

(Original Japanese version: published in August 2002)

1

Recent Trend of Immunology

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1.1 Introduction

The immune system is a biophylactic tool that is essential for humans living in symbiosis with various pathogenic microorganisms. Immunology is a science to understand and control the immune system. The development of immunology is expected to contribute not only to understanding basic life science, that is, search for life phenomena, but also to applications in the medical area such as clarification and conquest of infections, and immunological and allergic diseases, etc.

At the Kyushu & Okinawa Summit held in July 2000, measures against infections became one of the principal themes. Particularly, with regard to HIV/AIDS, tuberculosis and malaria, the reduction target up to 2010 was turned into a numerical goal, and the strengthening of measures to realize it was agreed on. The necessity of infection control and development of vaccines, etc., is still considerable throughout the world. In Japan, one out of three people has some type of allergy, and immunological intractable diseases (e.g., rheumatoid arthritis) attributable to the collapse of the immune system are increasing, representing one of the significant problems for modern medicine. To solve these problems, it is necessary to further promote immunological researches.

In the promotion strategy of prioritized areas (decided by the Council for Science and Technology Policy on September 21, 2001) based on the Science and Technology Basic Plan 2001-2005 (decided by Cabinet Meeting on March 30, 2001), "Clarification of the biophylactic mechanism dealing with environmental factors threatening Japanese people's health, prevention of diseases, and development of therapeutic techniques" was selected as one of the subjects in the field of life science, and the necessity for promoting immunological researches was indicated.

In this article, we will introduce the achievements of recent immunological researches, and, in addition, consider measures to further promote immunological researches.

1.2 Summary of immunology and achievements of recent researches

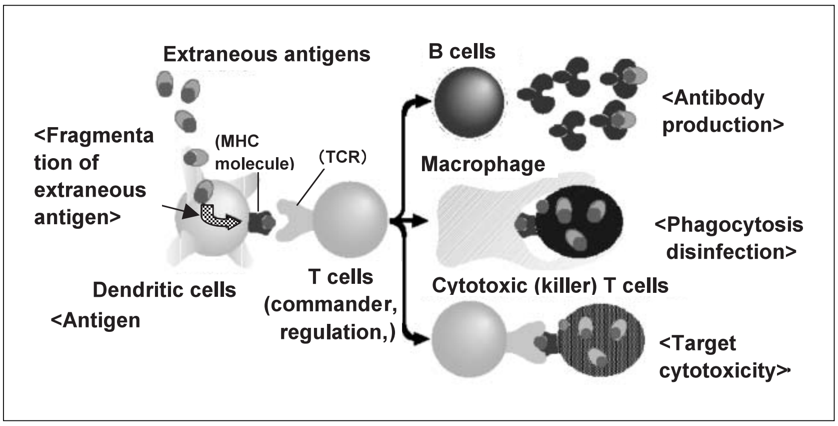
1.2.1 Immune functions

The immune system is a surveillance network distributed throughout the whole body as a self-defense against extraneous antigens (pathogenic microorganisms and foreign proteins, etc.), and has the function of attacking a foreign body for exclusion.

The cells involved in the immune response are white blood cells in blood. Of white blood cells, the principal cells involved in the immune response and the mechanism of the immune response are shown in Figure 1.

The extraneous antigens that invade into the body are fragmented into small peptides by antigen presenting cells such as dendritic cells, and are presented to helper T cells by major histocompatibility complex (MHC) molecules expressing on the surface of dendritic cells. Helper T cells that recognize this through T cell receptors (TCR) control B cells that produce antibody (immunoglobulin) specifically binding to antigen, macrophages that phagocyte antigen and disinfect, and cytotoxic T cells (killer T cells) that directly kill infectious cells such as those infected with a virus, in order to conduct the comprehensive regulation, etc., of the immune response. In addition, molecules called cytokines play an important role in the functions of

Figure 1: Main cells in charge of immune response



Source: The material prepared by prof. Yousuke Takahama of the Instute for at the Institute for Genome Research, University of Tokushima

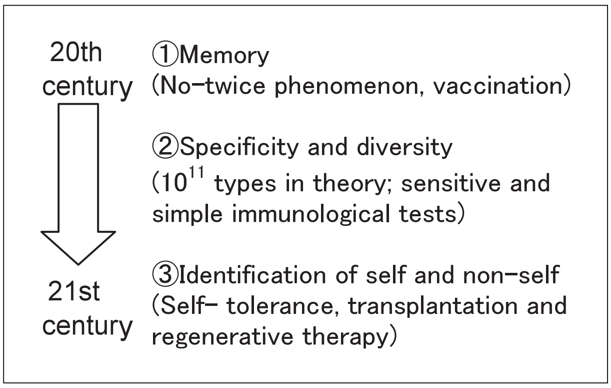
differentiation, proliferation and interactions of these immunocytes.

The immune system builds up a complicated network system in which these cells and molecules are highly controlled. A large number of various immunocytes and cytokines were identified owing to the progress of immunology up to now, and the principal functions, etc., were clarified.

1.2.2 Development of Immunology and Characteristics of the Immune System

Immunology originated in researches on the prevention of infections, and has been developed. With the development, various characteristics of the immune system have been revealed (Figure 2).

Figure 2: Three characteristics of the immune system



Source: The material prepared by prof.Yousuke Takahama of the Instute for at the Institute for Genome Research, University of Tokushima

(1) Memory

In 1789, based on the empirical fact that if a person's disease can be cured once, the person never develops the same disease again (no-twice phenomenon: immune memory), Edward Jenner (England) discovered that inoculation (vaccination) of pus of bovine smallpox in children could prevent the development of smallpox. In the late 19th century, based on the

Table 1: Diseases decreased through by vaccination in the United States

Disease name	Number of patients (persons)		Decrease rate (%)
	Maximum	1997	
Diphtheria	206,939	4	99.99
Measles	894,134	138	99.98
Mumps	152,209	683	99.55
Pertussis	265,269	6,564	97.52
Polio	21,269	0	100.00
Rubella	57,686	181	99.69
Congenital rubella syndrome	20,000 *	5	99.98
Tetanus	1,560 #	50	96.79
Influenza (< 5 years of age)	20,000 *	165	99.18

* Estimate, # No. of deaths

Source: Authors' compilation on the basis of the Nature Reviews Immunology, 2000 method of vaccination, Louis Pasteur (France) discovered that various livestock diseases could be prevented by using attenuated bacteria (vaccine therapy).

After that, the understanding of the phenomenon of immune "memory" that had been established up to the early 20th century and the spread of vaccines made great contributions toward saving many people throughout the world from various infections (Table 1).

(2) Specificity and diversity

The immune system produces antibodies specifically responding to numerous antigens. Since the latter half of the 1970s, genetic engineering was introduced into immunology, and it was proved that the mechanism to produce diverse antibodies was attributed to gene re-organization (a phenomenon in which recombination of gene fragments occurs to organize new genes). This achievement was brought about by Dr. Susumu Tonegawa, the first Japanese to win the Nobel Prize in Physiology and Medicine.

For human antibodies, if the number of diverse types is calculated from combinations of the number of gene locus (domain V, domain D, domain J), there are 2.6 x 106 types. Considering the addition of N sequence and the diversity (there are various theories of 105 to 1010) due to very frequent variations of somatic cells, a diversity of more than at least 1011 is likely.

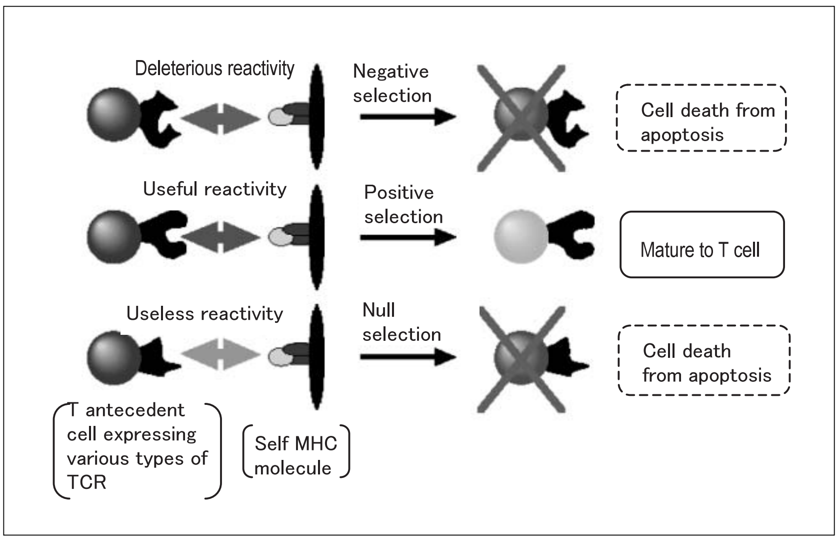
The clarification of the specificity and diversity of the immune system was a significant achievement of immunology in the 1970s to the latter half of the 1990s. The achievement is being utilized in many forms including clinical examinations such as cancer screening, detection of food poisoning bacteria, and tests for environmental chemical substances.

(3) Identification of self and non-self

Identification of "self" and "non-self" in the immune system is an important characteristic of such system. Clarification of the mechanism of self-tolerance, which excludes "non-self" but does not react to "self," is one of the greatest targets of modern immunology. When the mechanism of self-tolerance, which normally functions within the immune system, happens to collapse, an autoimmune disease may develop, and, as such, if it becomes possible to control the self-tolerance mechanism, the problem of rejection in transplantation and regenerative medicine may be resolved.

T cells, which play the most important role in the identification of "non-self," are produced in the thymus. Of hematopoietic stem cells produced in bone marrow, those that enter the thymus repeat rapid division and proliferation to produce a large quantity of early T cells. The early T cells are selected based on the reactivity of emerged T cell receptors (TCR) against the major histocompatibility complex (MHC) that is self

Figure 3: Selection of T cells in the thymus



Source: The material prepared by prof. Yousuke Takahama of the Instute for at the Institute for Genome Research, University of Tokushima molecule, and only those that received a "positive selection" mature to T cells (Figure 3).

The cells with a strong reactivity to MHC may possibly react to "self" in the future, and are judged as deleterious and receive a "negative selection" resulting in death. The cells without reactivity to MHC are judged as useless for future immune responses, and receive a "null selection" resulting in death. The cells with a moderate reactivity to MHC are judged possible to work and useful in the future, and receive a "positive selection" maturing to T cells. At that time, if the reactivity to MHC is too low, the cells cannot survive. Such strict selection in the thymus excludes more than 90% of early T cells.

If the process does not function well, it may become a cause of autoimmune disease, etc. A self-tolerance mechanism like this exists in peripheral lymphatic tissues other than the thymus, and such an abnormality in the immune control system may become a cause of developing autoimmune disease.

In recent years, researches on regenerative medicine and gene therapy are being conducted as important subjects. However, a significant problem that remains unsolved is that the medical techniques including embryonic stem cells (ES cells) and vectors (e.g., virus as a vector of gene) for gene introduction are rejected as "non-self."

At present, the rejection is suppressed by immunosuppressants, but there are many problems such as side effects due to the reduction of the patient's entire immunity, and the necessity for continuous treatment with the drugs. Thus, a solution from a new approach not dependent on immunosuppressants is being sought.

As a result, research attempting to solve the problem by clarifying the immune control mechanism, based on lymphocytes and the immune control molecules, in order to control the functions is currently one of the hottest themes.

1.2.3 One example of recent achievements in immunology

(1) Immune control system

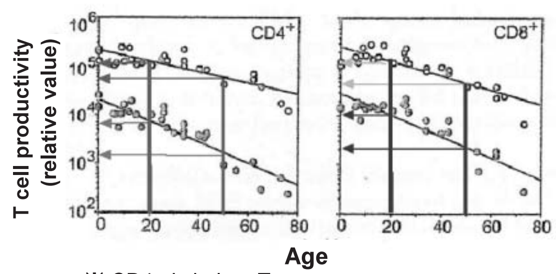
In recent years, the existence of T cells specializing in immune control was revealed, and as achievements of Japanese researchers, two types of immune control T cells ($CD25^+CD4^+$ T cells and NKT cells) were discovered. The functions of immune control T cells are maintenance of the take in organ transplantation, inhibition of the development of cancer and inhibition of allergy, and, further, their contribution to the inhibition of the development of autoimmune diseases was also revealed. Therefore, this discovery is expected to contribute to the resolution of immunological intractable diseases that remain unsolved up to now.

(2) Induction of acquired immune tolerance

The induction of acquired immune tolerance represents research to try to specifically induce immune tolerance by introducing a "non-self" ingredient (graft or vector) to the thymus and attempting re-programming of "self" postnatally. However, to realize this, the thymic functions must be working even in adults.

In the past, thymic functions in adults had been doubted because the establishment of "self" and "non-self" was said to occur during childhood, and after puberty the thymus was said to be replaced by fat tissue. However, a recent research by Douek (currently transferred to the National Institutes of Health, U.S.A.), who had belonged to Texas University South-Western Medical Center et al., using the TREC (a parameter to presume how much time passed after production of a certain T cell group in the thymus) revealed that the adult thymus is not completely replaced by fat tissue, and it continuously produces new T cells (Figure 4). Like this case, the basic concept of thymic functions began to be reviewed.

Figure 4: Age dependence of T cell productivity in the thymus



※ CD4+ is helper T cell.
CD8+ is cytotoxic (killer) T cell.

※ The two decreasing lines were measured

Source: Douek, et al.: Nature (1998)

(3) Molecular mechanism related to the thymic formation and functions

Researches to clarify the characteristics of the thymus have rapidly progressed. For example, some molecules such as a molecule involved in the maintenance and regeneration of thymic functions in the adult body, and a molecule involved in the thymic formation were known. However, the mechanism to form the thymus itself was not yet known.

Then, for example, among variants of medaka (*Oryzias* : ex., killifish), using a variant having no thymic development, an attempt to clarify the mechanism of the molecular structure that controls the formation of the thymic organ, its regeneration or development was started (a collaborative research by Professor Yousuke Takahama at the Institute for Genome Research, University of Tokushima, and Kondo's Induction and Differentiation Project, Exploratory Research for Advanced Technology (ERATO), Japan Science and Technology Corporation).

1.2.4 Entire picture of immunological researches

In Figure 5, the entire picture of immunological researches is shown.

Immunology has to date clarified many basic concepts including individual cells and molecules involved in the immune response, and the functions and relationship between immunity and diseases. Based on the achievements, clinical application of them was generally conducted including the prevention of infections and realization of transplantation therapy through the development of vaccines and immuno-suppressants, and the development of immune therapy using the immune response.

However, there are many new problems that remain unsolved. For example, it is still an important problem for the future to tackle emerging infectious diseases threatening today's people such as AIDS, and re-emerging infectious diseases such as malaria and tuberculosis.

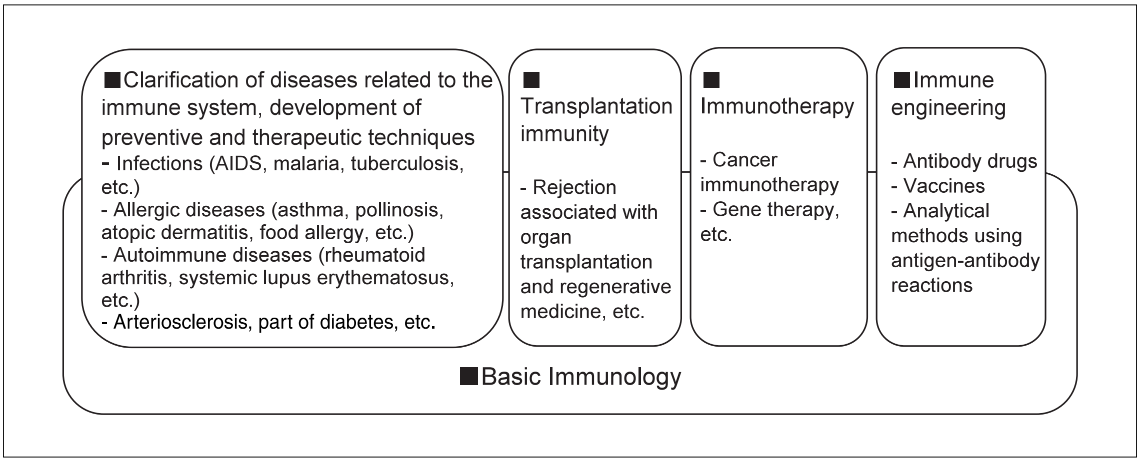
Allergic diseases and immunological intractable diseases have a tendency of increasing, and, in the therapies, development of a radical treatment based on the immune system is desired instead of the symptomatic therapy currently being conducted. As causes of the onset of allergic diseases, multiple factors such as stress and air pollution are considered to be involved, and it is necessary to clarify these in the future.

In the practical use of regenerative medicine and gene therapy, the problem of rejection in the immune system is an important problem to be solved.

In the future, it is necessary to promote research and development on the problems to meet the clinical needs, as well as the development of base technology such as database build up specifically for the immune system. In addition, it is imperative to promote translational researches that apply the results of exploratory basic researches to clinical studies.

In basic immunology, many areas remain to be clarified. Following this, it is necessary to promote individual immunological researches based on original ideas in order to understand the entire picture of the complicated immune system.

Figure 5: Entire picture of immunological researches



1.3 Research promotion system of immunology

1.3.1 Immunological researches in Japan

In our country, basic immunological researches have been promoted mainly by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and measures against infections and related clinical researches by the Ministry of Health, Labour and Welfare (MHLW). As a budget related to researches of immunology and allergy for fiscal 2002, approximately 5,300 million yen was allotted by MEXT, and approximately 1,300 million yen (Grant-in-Aid for Health Science Basic Research) was allotted by MHLW. In this other, 1,500 million yen was appropriated to emerging and re-emerging infectious diseases research, and 1,800 million yen was appropriated to AIDS countermeasure research.

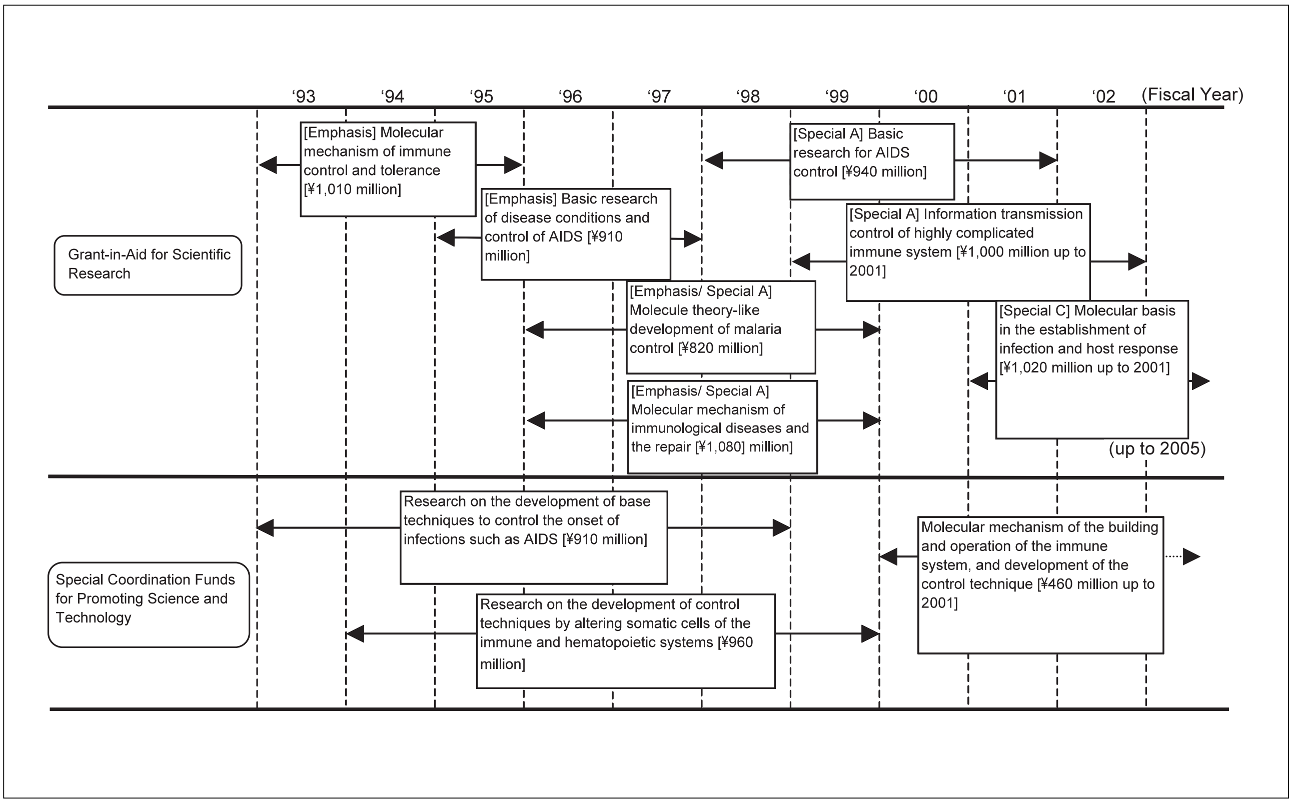
In Figure 6, the main achievements by the recent Grant-in-Aid for Scientific Research and the Special Coordination Funds for Promoting Science and Technology (SCF) are shown. In addition, as one of the researches of the Core Research for Evaluational Science and Technology (CREST) of the Japan Science and Technology Corporation, "Advanced medical techniques for immunological intractable diseases and infections, etc." was started in fiscal 2001.

In fiscal 2001, as the first public research organization in Japan established specifically for researches of immunology and allergy, the Research Center for Allergy and Immunology (RCAI) was started in the Institute of Physical and Chemical Research (RIKEN). RCAI has a similar form to that of American institutes, and all the staff from the head of the Center to the technicians are non-regular contract employees, and they are evaluated every 5 years in terms of achievements by an outside evaluation committee. RCAI aims to establish base technology such as development of DNA chips and building up of a database specifically for immunology, and to promote subject-setting-type of basic researches including allergy control and control of the onset of autoimmune diseases.

1.3.2 Immunological researches in the United States

Immunological researches in the United States are being conducted centering on the National

Figure 6: Achievements by the Grant-in-Aid for Scientific Research and the Special Coordination Funds for Promoting Science and Technology



Institute of Allergy and Infectious Diseases (NIAID), which belongs to the National Institutes of Health (NIH), and the Centers for Disease Control (CDC).

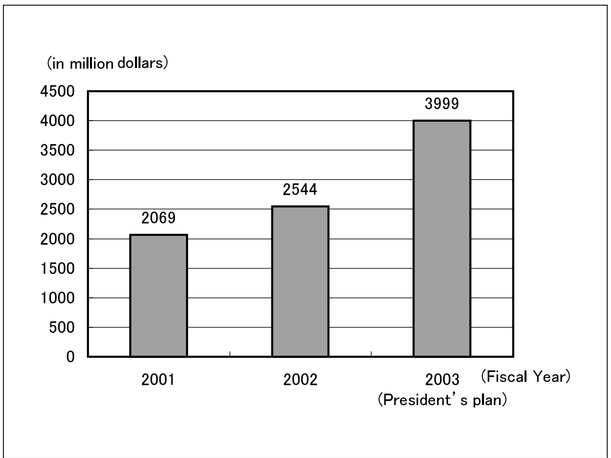
The NIAID is conducting researches related to infections such as AIDS, immunity-related diseases such as allergy and asthma, and vaccine development, together with other supporting researches.

In the President's budget plan for fiscal 2003, due to the situation that 2003 is the final year of the 5-year double budget campaign of NIH started in 1999, the budget of NIH for research and development was substantially increased by 17.5% compared to the previous year. In particular, NIAID is an organization at NIH that takes the initiative in measures against biological terrorism and AIDS research, and, among the institutes of NIH, the budget of NIAID was substantially increased* by approximately 4 billion dollars (approx. 480 billion yen), which corresponds to approximately a 57% increase compared to the previous year (Figure 7).

Details of the NIAID's budget for fiscal 2001 are shown in Figure 8. Research grants, such as research project grants, are usually for basic researches, and are grants for researches based on ideas of researchers at universities or research institutes. Not only the NIAID but also other institutes of NIH allot approximately 70% of their total budget to research grants.

*Tomoe Kiyosada, The Trend of the R&D Policy in the US - Transition of priority areas in the R&D budget allocation of the federal government —; Science & Technology Trends — Quarterly Review, No.4 (December 2002).

Figure 7: Fluctuation of the budget of NIAID



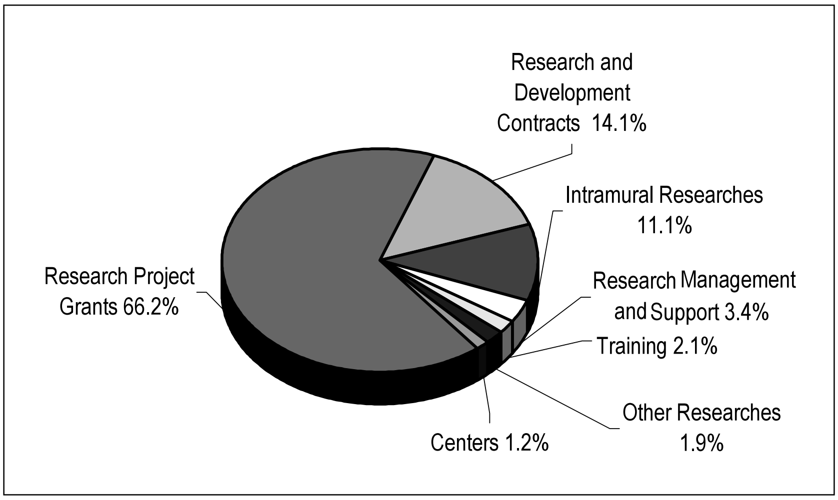
Source: Authors' compilation on the basis of the home page of NIAID

1.4 Conclusion

1.4.1 Directivity of the development of immunology

Today, in the field of immunology, there are many problems that remain unsolved including control of refractory infections such as AIDS, development of vaccines, clarification of the onset of allergic diseases and immunological intractable diseases, and development of preventive methods and therapies. High expectations are placed on regenerative medicine and gene therapy as state-

Figure 8: The Details of the budget for 2001 in NIAID



Source: NIAID Profile: Fiscal Year 2001

of-the-art therapies, but in order to put them to practical use it is necessary to develop a technique to control the self-tolerance mechanism. Following this, it is necessary to solve problems and develop base techniques to satisfy the clinical needs.

Immunology has clarified many basic concepts up to now including individual cells and molecules involved in the immune response, and the functions and relationship between immunity and diseases. However, many phenomena remain to be solved, and it is necessary to build up basic knowledge and findings further. In addition, it is necessary to comprehensively understand the entire picture of the immune system formed by the individual cells and molecules through their complicated mutual relationship.

1.4.2 Measures for promotion of immunology

In order to solve problems that would satisfy clinical needs, i.e. research and development related to immunological and allergic diseases and infections, as well as those that are politically emphasized, it is necessary to promote the following organized research and development.

- Depending on the problem (e.g., clarification of environmental factors in the onset of allergy), attempt to seek efficiency by means of project-type researches such as genome researches.
- Promote human resource exchange and research exchange by attempting to establish cooperation between main institutes such as RIKEN Research Center for Allergy and Immunology, and universities.
- In order to understand the entire picture of the immune system including genome information, extend efforts to promote the development of basic technology such as database build up specifically for the immune system.
- Promote measures for translational researches that apply the results obtained from basic researches to clinical practice, for example, by promoting cooperation between research organizations and the hospitals belonging to them, etc.

In order to develop basic immunology that can clarify unsolved phenomena of the immune system, it is necessary to promote personal-idea-type researches based on personal intellectual curiosity or original ideas. To realize this, it is necessary to enrich research aid such as the Grant-in-Aid for Scientific Research, which gives a large degree of freedom to individual researchers.

Immunology in Japan has to date shown achievements focusing on cytokine researches, which are highly appreciated throughout the world. It is necessary to improve the evaluation system in order to aim at promoting researches having international competitiveness and to develop a new area in immunology. For example, it would be necessary to make public the review sheet for evaluations in an attempt to open up such evaluations, and to seek greater internationalization by adding foreign researchers to the judges of evaluations.

Acknowledgements

Together with our investigation, this article was compiled based on the lecture "Recent trends of immunology" (given by Yousuke Takahama, Ph.D., professor at the Institute for Genome Research, University of Tokushima and team director of the Laboratory of Immune System Development, RIKEN Research Center for Allergy and Immunology) at the Institute for Science Technological Policy on June 5, 2002.

During our work to compile this article, Prof. Takahama provided us with guidance and supplied the related materials. We are also indebted to Masaru Taniguchi, M.D.,Ph.D., director of RIKEN Research Center for Allergy and Immunology and professor at Chiba University Graduate School of Medicine, for various information. We would like to express our heartfelt thanks to both of these persons.

(Original Japanese version: published in July 2002)

2

Present and Future of Bioresources (Biological Genetic Resources)

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2.1 Introduction

As it is often said, "no resource, no research," bioresources are inevitable in the life science area. Since bioresource includes various things, such as experimental animals and plants, model animals and plants, embryos, cells, tissues and organs, their collection, storage and supply must be carried out on a national basis.

Since the old days, bioresources have been collected and stored mostly from a naturalistic point of view. In recent years, gene functional analysis has become the dominant subject of research in the life science area, and the accumulation of resources has led to the determination of genomic sequences in various organisms. The determination of the genomic sequence in a species drastically increases the efficiency of gene function analysis in that species, so strategic maintenance of resources linked with the genome research is desirable.

To date, bioresources in Japan have been scattered among individual university laboratories, etc., and the information on their locations has not been open to the public for a long time. Therefore, smooth utilization of the bioresources within research communities was relatively difficult. In order to promote smooth utilization of the bioresources, organizations for storing and supplying bioresources, as well as systems such as contracts, etc., that ensure smooth transfer of materials, will play important roles.

This report summarizes the current status of bioresources in the life science area, and discusses bioresource maintenance adapted to genome research and politic measures for supporting resource centers, etc., for supplying high-quality bioresources.

2.2 What is bioresource?

2.2.1 Materials included in bioresource

The definition for the term "bioresource" has never been made explicit by any public organization in their science and technology policies. Nevertheless, in the area of life science, "bioresource" is generally acknowledged as a term representing research materials such as "strains, populations, tissues, cells, DNAs, etc., that are used as materials for research and development." Moreover, materials applied via fundamental research stages, such as food or feed plant species (varieties) and environment-cleaning micro-organisms, and human-related materials such as cells and tissues used in the medical area, are also included in bioresources (Table 1).

Table 1: Materials included in bioresources

Research materials	Strains, populations, tissues, cells, DNAs, etc., used as materials for research and development
Applied materials	Food and feed varieties, livestock, environment-cleaning organisms
Human-related materials	Human-related materials such as cells, tissues, etc.

Source: The material prepared by Professor Yuji Kohara of the National Institute of Genetics

Table 2: Classification of bioresources from the researchers' viewpoints

Classification	Materials
Produced during the research process	— Mutants — Transgenic organisms
Collected for conducting research	— Materials produced by researchers in the past (Escherichia coli, nematodes, Drosophila, mice, etc.)

Source: The material prepared by Professor Yuji Kohara of the National Institute of Genetics

2.2.2 How bioresources are generated

In recent years, studies for analyzing gene functions dominate the research in the life science area. In the process of such genome studies, various mutants and transgenic organisms (organisms artificially produced via genetic engineering) have been produced in large numbers.

Furthermore, when researchers attempt to elucidate a life phenomenon via gene functional analysis, they often collect species possessing certain characteristics concerning the target phenomenon from species generated by researchers in the past or from natural populations, and search the genes, etc., related to such characteristics. Therefore, species generated by researchers in the past or natural populations are stored by the researchers or resource centers, etc., as valuable bioresources.

Meanwhile, after researchers publish their research results, mutants and transgenic organisms generated during the research process are provided to other researchers as common research materials of the research community to ensure reproducibility of the results and enable comparisons of research results. Therefore, it is widely accepted that after researchers publish their works, they must store the bioresources generated during the research process and share them with other researchers.

2.2.3 Bioresource centers

When collection and management of bioresources are consigned to individual university laboratories, etc., some problems may arise, such as:

— Heavy burdens on researchers for collecting and managing materials over a certain size, over a certain period;

— Loss or quality deterioration of materials due to personnel changes in researchers, etc.; and

— Little chance of exploiting valuable bioresources within research communities due to difficulties in accessing information concerning bioresource locations.

Therefore, bioresource centers that are capable of collecting, managing and supplying bioresources should be established for each biological species or research area to realize unified supplying of bioresources to the research communities.

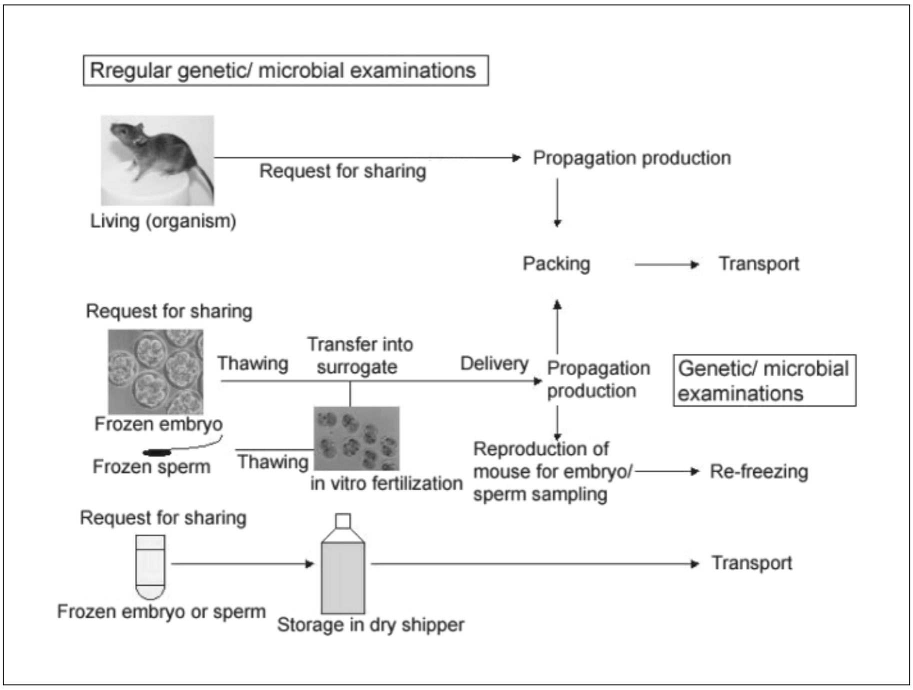
A bioresource center requires a large amount of labor and cost for maintaining and managing a great number of animals, microorganisms and other living organisms. As can be seen from the example of dealing with mice, supplying genetically or pathologically superior resources requires regular genetic or microbial examinations, as well as techniques for managing frozen embryos and sperms and propagation techniques such as in vitro fertilization. Consequently, the staff members must be highly specialized in such techniques (Figure 1). These techniques differ among various bioresources, depending on the species or levels of materials such as individuals, cells and DNAs. Therefore, bioresource centers must retain specialized staff members for each kind of bioresource.

In addition to supplying high-quality bioresources, bioresource centers are expected to lead the research community by:

— Reorganizing research results such as constructing genetic maps and assigning names to genes; and

— Supporting research from a comprehensive point of view by summarizing all data, ranging from the genetic backgrounds of the resources to the results of studies conducted using the resources.

Figure 1: Process for sharing mouse strains



Source : The material prepared by the Bioresource Center of The Institute of Physical and Chemical Research

All in full liaison with the research community and with authorized researchers playing the central role. This means that a bioresource center is not merely a research-supporting organization, but is the core of the academic area.

2.2.4 Bioresource and intellectual property rights

Recently, there are many cases where the results obtained from a genome research or other fundamental research directly lead to industrial applications. As a consequence, intellectual property rights are actively applied for bioresources, and certain restrictions (e.g., prohibition of direct application to profit-making activities, and prohibition of transfer to a third party) are imposed on the other parties in bioresource transfer contracts (MTA: Material Transfer Agreement). Meanwhile, researchers, especially from the standpoint of the developers of the resources, are demanding the development of new means to protect intellectual property rights on the resources themselves, which extends beyond the range of intellectual property rights covered by the existing patent laws.

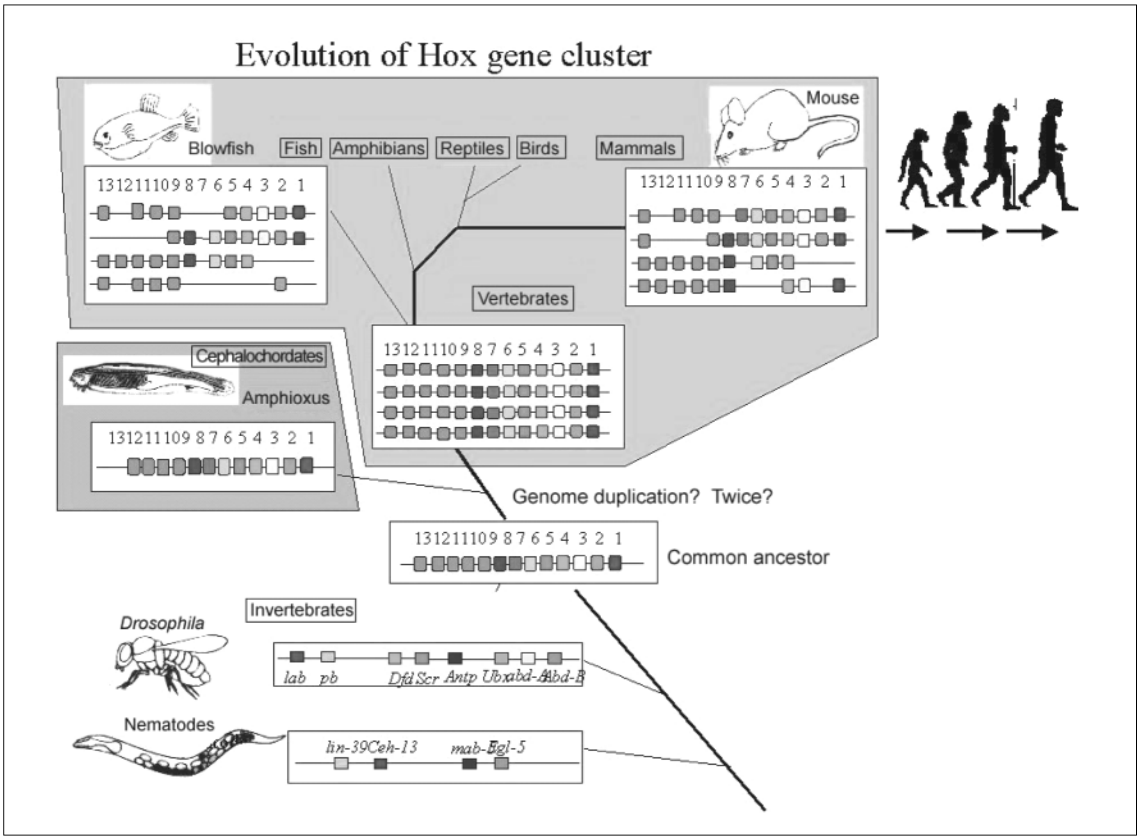
On the other hand, a reinforcement of intellectual property rights imparted to resource developers may raise the price of the resources or hinder smooth access to the resources by the research community. Many researchers warn, "Excessive assertion of intellectual property rights for bioresources may deprive life science of novel discoveries."

2.3 Importance of bioresources in the genome age

Genome sequences, the integral part of the genetic information of organisms, have been identified in microorganisms including pathogens, industrially useful bacteria and yeast that have been genetically studied in detail. Subsequently, genomes for multicellular organisms such as nematodes and *Drosophila* have been sequenced, and mammalian genomes have also been roughly sequenced (draft sequence) in mice and human beings.

In recent years, comparative genomic analyses among various organisms have led to a hypothesis that the evolution of organisms can be explained as the evolution of genomes. For instance, the comparison of the Hox gene family that controls morphogenesis among various species has revealed that invertebrate genomes had duplicated twice resulting in a 4-fold increase as they evolved

Figure 2: Evolution of organisms and Hox gene



Source: The material prepared by Professor Yuji Kohara of the National Institute of Genetics

into vertebrates (Figure 2). The basic structures of Hox genes are similar between fish and mammals, suggesting that the gene composition has not changed drastically since the appearance of vertebrates.

Once the entire genomes are sequenced for various organisms, the diversity of organisms may be revealed at a molecular level, based on the sequence comparison of not only the specific genes but also the entire genome. In addition, since a gene whose function has been revealed in a certain species has its homologues (genes with closely related structures) in various other species, the efficiency of gene function analysis should be drastically increased by comparative genomic analysis among species whose genomes have been sequenced. In other words, animals, plants and even microbes can be used as model organisms for elucidating the functions of human genes.

For a model organism with established experimental systems, bioresources such as mutants must be reorganized in linkage with genome sequences. Elucidation of various life phenomena with such model organisms is inevitable for technical development in the medical and industrial areas, so the importance of bioresource is increasing more and more in the genome age.

2.4 Current status of bioresource organizations and the related policies

2.4.1 History of bioresource organizations in Japan

With a few exceptions, the great number of various biological resources in our country and their information are collected by individual universities or specialized organizations based on their own standpoints. Most of them have been available for internal use only, leaving few open to the public.

Organizations of bioresources and the related information bases are important research bases in the area of life science. Such recognition among researchers and administrative departments has led to the suggestion of "the organization of research and development bases" as a policy for the Science and Technology Basic Plan decided by the Cabinet in July 1996, based on the Science and

Table 3: Organization of bioresources in universities, etc.

1997	Cultured cells: Institute of Development, Aging and Cancer, Tohoku University
"	Barley: Research Institute for Bioresources, Okayama University
"	Silkworm: Faculty of Agriculture, Kyushu University
"	Mouse, rice, Escherichia coli: National Institute of Genetics
1999	Drosophila: Kyoto Institute of Technology

Source: The material prepared by Professor Yuji Kohara of the National Institute of Genetics

Technology Basic Law. Specifically, "improvement of the information infrastructure" was mentioned, in addition to "improvement of research and development facilities and equipment" and "the promotion of a research-informational infrastructure." Concerning the "improvement of the information infrastructure," it has been declared that "it is important to organize, collect, store and accumulate standards, evaluation methods for examinations, bioresources, genetic resources, materials, etc., for the stable, efficient promotion of research and development activities, etc. Moreover, the above-mentioned standards, materials, etc., must be supplied widely to promote their broad diffusion throughout the country."

In association with such movement for bioresources in universities, etc., which have accounted for a major portion of the bioresources used in the life science area in our country, the Science Council announced "A report on the application of bioresources for academic research" in June 1996, and bioresource centers for each kind of bioresource was established as university affiliates, etc. (Table 3).

Combined with the establishment of bioresource centers, construction of databases and networks concerning bioresources was initiated to reinforce the intellectual basis. The National Institute of Genetics established the Genetic Resource Information Center in 1997, and started their Genetic Resource Information Databank Division the following year. In cooperation with the Resource Conservation Division, the center is constructing and disclosing a bioresource information database (SHIGEN: SHared Information of GENetic resources), mainly targeting bioresource centers.

Meanwhile, databases for the bioresources, including applied and human-related materials presented Table 1, have been enriched in the gene bank of the National Institute of Agrobiological Science under the Ministry of Agriculture, Forestry and Fisheries, the Japan Health Science Foundation, the National Institute of Health Science and the National Institute of Infectious Diseases under the Ministry of Health, Labor and Welfare, and the National Institute for Environmental Studies under the Ministry of the Environment.

2.4.2 The National Bioresource Project

The projects mentioned in Section 2.4.1 have advanced the organization of bioresource in the life science area to a certain extent. Yet, the progress in genome research has increased the importance of the organization of intellectual bases in the life science area. Taking this into consideration, the Ministry of Education, Culture, Sports, Science and Technology started the National Bioresource Project from 2002.

Among the bioresources such as experimental animals and plants, stem cells such as ES cells (embryonic stem cells) and gene materials of various organisms, this project aims at establishing a system for the systematic collection, storage, supplying, etc., of materials that need to be strategically organized under government control. The goal is to establish a bioresource organization system at the world's highest level by 2010.

As shown in Table 4, in 2002, core bases for each of the 23 resources are to be established for systematic collection, storage, supplying, etc., of the resources, as well as information centers for summarizing and providing information on the locations of various resources and genetic information. The total project expense for 2002 is 4.4 billion yen.

Table 4: Summary of the National Bioresource Project

I. Core Base Establishment Program		
Experimental Animals	— Mouse (development • storage • supplying)	RIKEN BRC
	— Mouse (mutagenesis)	RIKEN GSC
	— Rat	Animal Experiments of the Faculty of Medicine, Kyoto University
	— *Drosophila*	Kyoto Institute of Technology
	— Nematodes	Tokyo Women's Medical University
	— *Xenopas*	Amphibian Laboratory, Hiroshima University
	— Silkworms	Faculty of Agriculture, Kyushu University
	— Cyprinodont	Bioscience Center, Nagoya University
Experimental Plants	— *Arabidopsis*	RIKEN BRC
	— Rice	National Institute of Genetics
	— Wheat	Faculty of Agriculture, Kyoto University
	— Barley	Research Institute for Bioresources, Okayama University
	— Algae	National Institute for Environmental Studies
	— *Chrysanthemum*	Plant Gene of Hiroshima University
	— Morning glory	Faculty of Science, Kyushu University
Microbes	— Pathogenic microbes	Research Center for Pathogenic Fungi and Microbial Toxicoses, Chiba University
	— *E. coli*	National Institute of Genetics
	— Yeast	Faculty of Science, Osaka City University
Primates	— Japanese macaque	National Institute for Physiological Sciences, Okazaki National Research Institute
	— Chimpanzee (investigation)	Faculty of Agriculture, Tokyo University
Cells/ DNAs	— Animal and plant cultured cells, tumor cells, DNAs, etc.	RIKEN BRC
Human cultured cells	— ES cells	Institute for Frontier Medical Science, Kyoto University
	— Standard human cultured cell strains (investigation)	Institute of Development, Aging and Cancer, Tohoku University
II. Information Center Establishment Program		National Institute of Genetics

Source: The material prepared by the Life Science Section, Ministry of Education, Culture, Sports, Science and Technology

2.4.3 Main bioresource centers overseas

Bioresource organization is most advanced in the United States among other foreign countries. There, large-scale core bases were already established during the early period. In most cases, Japanese researchers cannot conduct their research and development without the resources supplied from the U.S. and other foreign countries.

Jaxon Laboratory, one of the world's largest bases in the U.S. for supplying experimental mice that are widely used in basic and applied research in the life science area, was founded in the 1930s. ATCC (American Type Culture Collection), known as a microbe-supplying base in the U.S., also has a long history with its foundation back in the 1920s. These institutions are non-profit organizations, receiving financial support from NIH.

At Jaxon Laboratory, the total project expense for 2000 was 88.1 million dollars (approximately 50% shared by NIH, mouse sales earnings were 34.2 million dollars), and the number of staff members was 1,022 (260 of which were researchers). None of the core bases in Japan has a scale comparable to this. Furthermore, Jaxon Laboratory possesses over 2,700 mouse lines, supplying about 2 million mice to universities, etc., per year. On the other hand, merely 619 mouse lines (as of July 2002) have been submitted to the Bioresource Center of The Institute of Physical and Chemical Research (RIKEN BRC), which is the largest core base in Japan.

2.5 Conclusion

In our country, the Ministry of Education, Culture, Sports, Science and Technology has started the National Bioresource Project as its policy from 2002. The establishment of the core bases for individual organisms and a genetic resource center network that links them are currently in progress, with the academia playing the leading role. Researchers in universities, etc., are also expecting that the project will improve, to a certain extent, the situation in which bioresources have been scattered among individual university laboratories, etc., preventing their effective use within the research

Table 5: Main Bioresource Centers Overseas

U.S.	Europe
• **NIH(National Institutes of Health)** Financially supports institutions storing research resources for research and projects • **NCI(National Cancer Institute, NIH)** General support • **NCRR (National Center for Research Reources, NIH)** Supports resources for research ranging from medical to general biological studies • **ATCC (American Type Culture Collection)** Virus, bacteria, cells, fungi, cultured plants, protista, and yeast • **CCR(Coriell Cell Repositories)** Human cells derived from human hereditary diseases • **FGSC (Fungal Genetics Stock Center, University of Kansas Medical Center)** Shares fungi • **CDC (Centers for Disease Control and Prevention)** Pathogenic microbes • **JAX (Jackson Laboratory)** Mice • **ZFIN (Zebrafish Information Network, University of Oregon)** Zebra fish • **Fly stock(Bloomington Drosophila Stock Center, Indiana University)** *Drosophila stock center* • **National Resource for Aplysia Facility, University of Miami** Sea hare • **National Resource Center for Cephalopod, The University of Texas Medical Branch** Cephalopoda • **CABRI (Common Access to Biotechnological Resources and Information)** Summarizes information from bioresource institutions in Europe	(U.K.) • **UKNCC (United Kingdom National Culture Collection)** Union of 10 institutions collecting microbes, animal cells, and plant cells • **CABI (CAB International)** Provides genetic resources and identification and examination services for various species • **CAMR (Centre for Applied Microbiology & Research)** Provides biological and medical research resources • **ECACC(European Collection of Cell Cultures)** Shares animal cultured cells • **NCIMB (National Collection of Industrial and Marine Bacteria)** Shares industrial and marine microbes • **NCTC(National Collections of Type Cultures)** Bacteria, fungi, micoplasma, plasmids, and transposons (Holland) • **CBS (Fungal Biodiversity Center - Utrecht, The Netherlands)** Institution collecting fungi, yeast and bacteria (Germany) • **DSMZ(German Collection of Microorganisms and Cell Cultures)** Collects microbes and animal cultured cells (France) • **Institut Pasteur** Mainly microbes and plasmids (Belgium) • **Belgian Co-ordinated Collections of Micro-organisms (BCCM)** Holds and shares fungi and yeast strains as type strains

Source: The material prepared by Dr. Hiroshi Mizusawa of the National Institute of Health Science

communities.

Meanwhile, the prices of bioresources are unstable, being affected by the research trend in the life science area. Since the education of human resources for handling the bioresources requires the promotion of policies on a long-term basis, future follow-up is inevitable.

When promoting the policies, the following points must be considered.

2.5.1 Short – and long-term, balanced support policies

In the life science area, the main research subject has changed from phenomenon to phenomenon along with time. Consequently, the values of the bioresources have also changed. For example, mutants and transgenic organisms are artificially produced in large amounts in the process of genome research, but once they accomplish their roles as tools for analyzing gene functions, they are no longer valued. Furthermore, such materials can be reproduced if required in some cases. Therefore, support policies with time limits are urgently required for such materials.

On the other hand, there are many irreplaceable resources that cannot be artificially produced, such as natural subspecies and related species. Therefore, a good balance between short- and long-term policies is required, such as developing an inexpensive, resource-storing technique while promoting permanent collection and management of the resources.

2.5.2 Continuous support policies concerning human resource education

As mentioned in Section 2.2.3, bioresources; (1) shows uniqueness in their maintenance and propagation techniques for individual species, and (2) are highly valued for the information on their genetic backgrounds. Therefore, it is important to educate specialists for maintaining and managing the resources.

In policies such as the National Bioresource Project, resource centers that are affiliates of universities or other public research institutions are exclusively employed as the core bases, and the government offers the financial support required for collecting and supplying the bioresources. On the standpoint of educating specialists, not only short-term financial support but also mid- to long-term support policies for ensuring human resources are required.

Bioresource centers in the U.S. and European countries not only have large-scale facilities but also have well-established personnel systems for technicians to allow their promotion. Holding technicians in high esteem encourages the education of human resources specialized in bioresource management. There is a differentiation of roles between researchers and technicians, where the roles for good researchers are to map out policies for resource management or to give instructions to the technicians.

2.5.3 Bioresources and genome information

Currently, information concerning bioresource management is mainly centered on the location of resources, and the genetic information of the resources is only partly included. Furthermore, information on bioresources accompanying the information on genomes, such as their genomic sequences (e.g., information on the kind of bioresource from which the genomic data was obtained), lacks uniformity in the style of description and is not necessarily well established.

Assuming that gene function will be analyzed in various species in the future, genomic data will become closely linked with the information on the traits at an individual level, so information on bioresources accompanying genome information should become more and more important.

As a conclusion, for databases of genomic data such as the sequence data, it is important to contemplate how to organize an ontology*1 concerning bioresource information.

Acknowledgment

The present report was prepared based on the lecture "Current Status of Bioresources and Domestic Policies" given by Professor Yuji Kohara, head of the Genetic Resource Information Center, vice director of the National Institute of Genetics, on July 25, 2002 at the National Institute of Science and Technology Policy, and supplemented by information obtained through research conducted by the authors.

Finally, we would like to thank Professor Kohara for kindly offering guidance and the related materials during the preparation of this manuscript.

Glossary

*1 Ontology

Well-disciplined vocabulary or description method, free of unique concepts or terms defined for individual research subjects.

(Original Japanese version: published in September 2002)

3

Research Trend in LSI Technologies
— Report on Presentations at the VLSI Symposia and the Silicon Nano-electronics Workshop —

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3.1 Introduction

The annual "VLSI Symposia" ("VLSI Symposia on Technology and Circuits") and "Silicon Nano-electronics Workshop" (hereafter "Nano-electronics Workshop"), both of which are among major international conferences on LSI technologies, were held in Hawaii, US, in mid-June this year. The two conferences have been organized by the IEEE and annually held by Japan and the US in turn.

The VLSI Symposia consist of the "Symposium on VLSI Technology" (hereafter "Technology Symposium"), which concerns device technologies, and the "Symposium on VLSI Circuits" (hereafter "Circuit Symposium"), which discusses circuit technologies. Both symposia cover the latest technologies currently in use and those technologies under development for 1 to 2 generations ahead (for this year's events, 130nm to 65nm generation). Presentations are made mostly by private enterprises. This year, there were 86 presentations (of them, 2 were keynote speeches) for the Technology Symposium and 88 (4 were keynote speeches) for the Circuit Symposium. Combined, the participants totaled approx. 600 people.

The Nano-electronics Workshop focuses on more futuristic technologies. This conference is important since it may indicate a course of direction for future LSI technologies. Most presentations are given by universities. This year, there were 56 presentations (of them, invited research papers accounted for 6 and posters 27), and the participants amounted to approx. 200 people.

This report will explain some of the topics of these international conferences.

3.2 This year's trends

3.2.1 VLSI Symposia

(1) Technology Symposium

It has long been pointed out that simple scaling (i.e., miniaturizing device structures to increase integration and operating speed) is nearing its limit. New device structures, such as high-dielectric constant (High-k) gate insulation film*1, low-dielectric constant (Low-k) insulation film*2 and SOI (Silicon on Insulator)*3, are attracting much attention and some of them have already been commercialized. At this year's symposium, a total of 16 presentations were made concerning the high-dielectric constant (High-k) gate insulation film. Concerning the material for the film, silicon oxynitride (SiON) is the leading candidate for the immediate future, while hafnium oxide (HfO_2) is the potential candidate for the 65nm generation or later, and there were a large number of presentations on these two subjects. However, High-k gate insulation films share a major drawback in common: their carrier mobility, which directly affects the working speed of a transistor, is lower than conventional SiO_2 gate insulation films. The solution to this problem is nowhere in sight, and this disadvantage has been a stumbling block to commercializing High-k gate insulation films.

This year's symposium has a new session concerning the strained Si structure, which attracted attention at last year's Nano-electronics

Workshop (see "Science & Technology Trends-Quarterly Review" No.2 and No.4), and there were 4 presentations on this subject. In addition, IBM presented a device that used a High-k gate insulation film and the strained Si structure in the highlight session. (also see the July 2002 issue of "Science & Technology Trends", Topics part)

Another characteristic of this year's symposium was that those presentations on SoC (System on Chip, which integrates a processor, memory and analog circuits onto a single chip), non-volatile memories, analog devices and high-frequency devices gained much attention as a reflection of the fact that mobile devices have become widespread and have improved their performances, and the wireless LAN market has begun to expand. In contrast, there were fewer presentations on "DRAM Technology" sessions, indicating that the status of DRAMs as a technology driver has lowered.

Concerning the next-generation lithography*4, which will be the key to miniaturization, there were presentations on F_2*4 and EPL (Electron Projection Llithography)*4. However, it has been questioned whether equipments, masks and processes will be developed in time for the 65nm-generation LSI (expected to be mass-manufactured from around 2007). Therefore, a presentation on a mask technology that may prolong the life of ArF*4 — used in 130nm to 100nm generation — into the 65nm-generation LSI, drew considerable attention. This will be discussed in the next chapter.

(2) Circuit Symposium

Presentations on SoC also attracted attention in the Circuit Symposium. In addition, as for non-volatile memories, those presentations on the current mainstay multi-thresholding technology for flash memories (i.e., storing multi-bit signals in a single memory cell), and the next-generation memories such as the magnetic memory (MRAM)*5 and the ferroelectric memory (FeRAM)*5, attracted much attention.

Other notable presentations included those concerning low power consumption technologies. Low power consumption is an important performance indicator for mobile devices and home electric appliances. And the problem of heat generation that increases in conjunction with intensified integration and speeding up is becoming serious even for high-performance devices like PC processors. There was a heated debate in a panel discussion on this problem. At the panel discussion, Mr. Mizono of NEC pointed out that since each chip has a heat generation limit, the speed of performance increase would be almost halved from the current 3 folds per generation. Although measures to cope with this problem were suggested, such as specially designed packages and transistors and cooling methods, there seems to have been no decisive measure. Mr. Ito of Hitachi stressed that new concepts should be developed such as a processor based on a memory architecture.

In the keynote speeches, MEMS*6 was mentioned in both the Technology Symposium and the Circuit Symposium. In the Technology Symposium, Dr. Esashi of Tohoku University, and in the Circuit Symposium, Dr. K.D. Wise of the University of Michigan, gave presentations. In particular, Dr. Wise indicated the application in an implant treatment device with which a MEMS chip is implanted into the human body. The chip comprises medication delivery systems, sensors and controllers. The chip size is 0.5mm square or less, it receives power from a source outside the body via an microwave. Since it can control muscles by electrically stimulating nerves, studies are being conducted on the application of the chip for patients with malignant nervous diseases such as Parkinson's disease.

3.2.2 Nano-electronics Workshop

What became the center of attention in this year's Nano-electronics Workshop as a future technology that follows the strained Si structure was a transistor having a 3D structure called "FinFET." It will be discussed in detail in Chaper 3.4.

Concerning technologies in the nano-tech category, those presentations using highly feasible structures for devices, such as quantum dots, were especially notable. By contrast, there was only one invited speech given by IBM regarding the carbon nano-tube transistor. Since most of these nano devices operate only at ultra-low temperature, how to design nano devices that can operate at room temperature was hotly debated. It seems

Table 1: Roadmap for LSI sizes and lithography in ITRS2001

	2001	2002	2003	2004	2005	2006	2007	2010
DRAM 1/2 pitch	130	115	100	90	80	70	65	45
MPU 1/2 pitch	150	130	107	90	80	70	65	45
MPU Physical Gate Length	65	53	45	37	32	28	25	18
Optical lithography		ArF				F_2		EPL EUV

(Unit : nm)

Source: Author's compilation based on ITRS2001 (International Technology Roadmap for Semiconductors, 2001 edition), etc

that it will take much more time before this problem is solved.

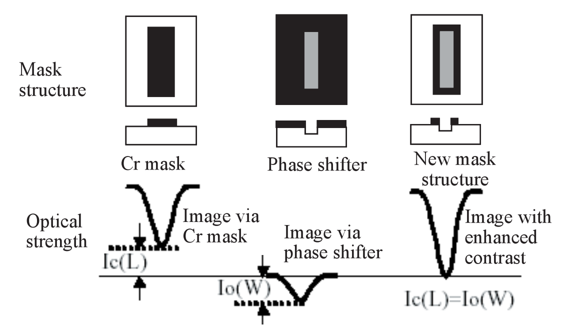
3.3 Next-generation Lithography

According to the latest roadmap for lithography (Table 1), which is the key to miniaturization, F_2 represents the 65nm generation and the electron projection lithography (EPL) or the extreme-ultra violet ray lithography[*4] (EUV) represents later generations. However, since F_2 lithography devices will likely be only effective for the 65nm generation and because of technological difficulties, western semiconductor manufacturers including Intel are shifting to EUV (see April 2001 issue of "Science & Technology Trends"). These movements seem to be also affecting Japanese semiconductor manufacturers.

At this year's event, Selete[*7] demonstrated that development resist for F_2-Lithography had been under way. In the meantime, Matsushita pointed out that EPL was superior to ArF and F_2 in focal depth and resolution. Matsushita also presented a mask technology for prolonging the life of ArF (used for the 130 to 100nm generation) for the 65nm generation, and attracted much attention (Figure 1). It is a kind of resolution enhancement technologies having a phase-shifting (shifting 1/2 light wave length) area in the middle of a printed pattern, thus to interfere with the surrounding lights; this technology is said to improve the focal depth and resolution as required for the 65nm generation even with an ArF lithography equipment. And, it is also notable that unlike conventional phase-shifting masks that can be applied only for repeated patterns (inverting the phases of adjacent patterns and enhancing the contrast using the interference), this technology can be applied even to isolated patterns.

Concerning the F_2 lithography, ASET[*8] presented its research findings this June to point out that although the development of laser, mask materials and resists has been proceeding, there are still problems such as difficulties in mass manufacturing calcium fluoride lens[*9], weakness of pellicle material that protects mask, and long-term durability against the burning of a contaminant. As for EPL and EUV, it is presently uncertain whether the development of masks and processes will be completed in time, and the prolongation of ArF's life is becoming the leading candidate for the next-generation lithography in terms of reducing the growing cost. By the way, in Japan, a total of 10 companies launched the Extreme Ultraviolet Lithography System Development Association (EUVA) this May in order to commercialize EUV for the 45nm and later generations.

Figure 1: Contrast enhancing technology presented by Matsushita



With a pattern having a line width below the wavelength, the image is blurred due to optic diffraction (left). The phase of light that passed the phase shifter is inverted with that of surrounding lights (center). When synthesizing both, the blurred area is compensated and the pattern contrast is enhanced (right).

Source: Author's compilation based on A. Mikasa et al., the "2002 Symposium on VLSI Technology Digest of Technical Papers," p. 200 (in 2002), etc.

3.4 Next device structure — FinFET

What gained much attention at the workshop as the next-generation technology following the strained Si structure was the FinFET structure. FinFET is a 3D structure in which the gate electrode is positioned around a channel (a transistor's part where an electric current passes) formed like a thin fin (see Figure 2). It is expected that FinFET will achieve faster operation, greater ON-stage current and less leakage current (less power consumption) than the current planar structured transistor. In addition, FinFET allows the creation of a finer transistor than the smallest possible size with lithography through the refined process. Dr. C. Hu from TSMC of Taiwan (the inventor of FinFET who also serves as a professor at UC Berkeley), who delivered an invited speech, demonstrated the properties of a FinFET prototyped at TSMC. He also stated that leading companies including IBM, Motorola and AMD are currently studying similar structures, and FinFET is among the leading candidates for the transistor structure in and after 2010.

TSMC also gave a detailed presentation on a FinFET with a gate length at 35nm (equivalent to the 65nm generation) in the VLSI Symposia. The presentation indicated that FinFET would demonstrate adequate performance even without introducing new materials like a High-k gate insulation film. Also, Motorola gave a presentation on FinFET's basic properties at the workshop.

FinFET has one drawback: its channel is too narrow to allow sufficient electric current. However, Dr. Hu showed a structure that allows sufficient electric current by forming multiple channels in a single transistor.

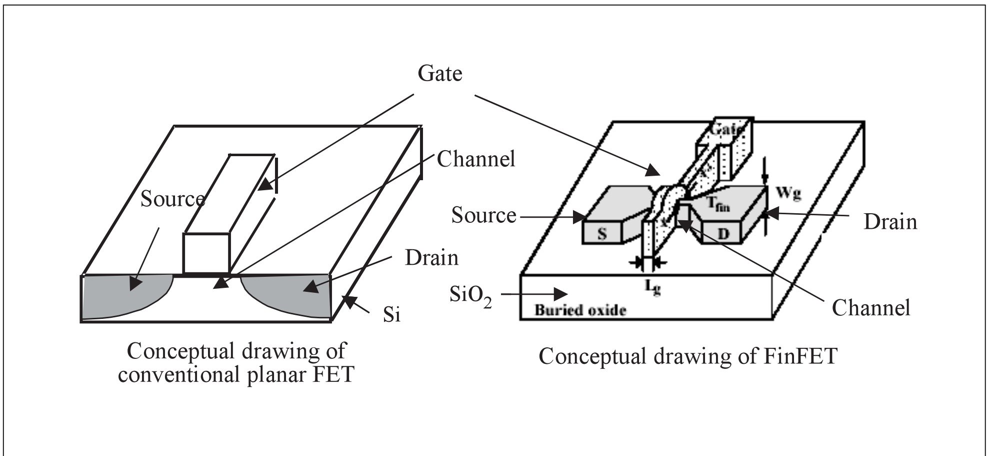
In contrast, a few presentations were delivered indicating that with the conventional planar FET, the surface roughness of the gate disturbed the travel of electric charge degrading the FET's performance. With the FinFET structure whose fin is formed by etching, it is anticipated that the roughness of the gate surface will be greater than that of the planar FET. This may become a problem in the future.

3.5 Research and development trends by country

In closing, this section will briefly analyze research and development trends by country in terms of the number of papers presented at the conferences. Table 2 shows the numbers of papers at each conference by country and region. These numbers include that of invited speeches, keynote speeches and poster sessions, but exclude panelists at panel discussions.

At both symposia, Japan and the US represented almost the same numbers. Given that the share of the Japanese semiconductor industry on the recent international market is dropping, and that the symposia were held in the US, it can be said that Japan made a good showing. South Korea ranked third to outperform Europe, and Taiwan also raised its presence. The 3 papers in the row

Figure 2: FinFET and conventional planar FET



Source: Author's compilation based on R. Yang et al., "2002 Symposium on VLSI Technology Digest of Technical Papers," p. 104 (in 2002), etc.

Table 2: Numbers of papers by country/region

Country/region	Technology Symposium	Circuit Symposium	Nano-electronics Workshop	Si Nano-electronics Workshop in 2001
Japan	35	37	8	18
US	32	42	25	6
Europe	8	2	9	7
South Korea	12	5	10	5
Taiwan	4	2	2	0
China	0	2	0	0
Other	1	3	0	0

Note: Overlapping papers through joint presentations are included.

Source: Author's compilation based on the proceedings of the conferences.

marked "Other" for the Circuit Symposium indicate theses presented by Canadian universities, and Canada has established a certain position in the field of circuit technologies.

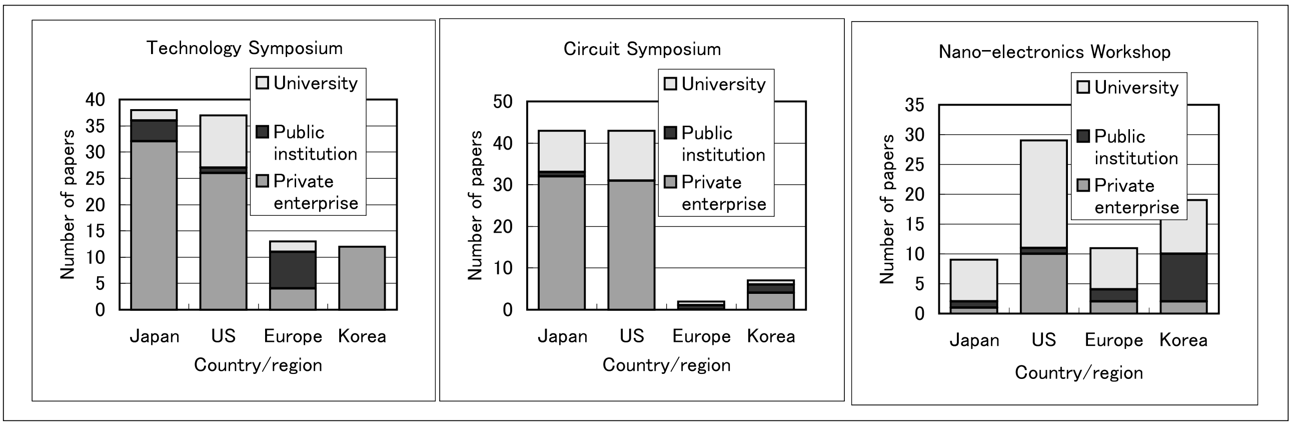
However, for the Nano-electronics Workshop, there were fewer Japanese papers than other major countries. This is due to the symposia's characteristic that the event is held by the US and Japan in turn, and every year the number of the host country's papers is much greater than that of the other. On the other hand, South Korea ranked second superceding Europe and Japan. This indicates that research activities in future technologies have also become more vigorous in South Korea. For reference, figures (numbers of papers by county and region) for the 2001 conference, held by Japan, are added to Table 2.

Figure 3 shows the numbers of papers presented by the top 4 countries/region for each conference. In these graphs, joint-research organizations each involving multiple companies, such as Selete of Japan and IMEC*10 of Europe, are categorized as "public institutions."

It is clearly indicated in the graphs that the two symposia were mostly represented by private enterprises, while the Nano-electronics Workshop was accounted for mainly by universities.

The Circuit Symposium graph indicates that Japanese universities made a strong showing. In the Technology Symposium, however, there was actually only one presentation by a Japanese university (one of the two presentations was a keynote speech). This was partially because it was held in the United States, but the fact that there are fewer universities in Japan that have facilities necessary for research into cutting edge devices is probably another reason. In fact, US universities represent a majority number of papers just because a limited number of universities equipped with important facilities made a large number of presentations. The reason for the large proportion of European public institutions is that IMEC and

Figure 3: Numbers of papers at each conference by institution



Note: Overlapping papers through joint presentations are included.

Source: Author's compilation based on the proceedings of the conferences

French CEA*11 made presentations in the form of joint research and the likes.

In the Nano-electronics Workshop graph, public institutions from South Korea represent a large proportion. In particular, a combination of ISRC (Inter-University Semiconductor Research Center) and Seoul National University accounted for most of those presentations. Of the 10 South Korean papers in 2002, 7 were presented through this combination. ISRC is a semiconductor research facility established in 1989 within the site of Seoul National University and jointly owned by several universities. It also serves as an industry-academic joint research center. If more universities use ISRC in the future, the number of South Korean papers may further increase.

3.6 Conclusion

It has been learned through the conferences that individual technologies for the 65nm and later generations are steadily advancing. In addition, it is gradually becoming clear which of the technologies will be the mainstay in those areas where there are multiple-technology options such as lithography. However, it appears that a favorite has yet to be determined. If the technologies to be used are not determined in the coming 2 years or so for starting production of 65nm-generation devices in 2007 as planned in the roadmap, the building of LSI designing and manufacturing lines may not be completed in time.

Concerning the numbers of papers by country, presentations by South Korea and Taiwan are increasing. In the future, it is expected that presentations from China will also increase, and the presence of Asia will further grow.

Glossary

* 1 High-dielectric constant (High-k) gate insulation film

With the FET (Filed-Effect Transistor), which is currently the mainstay transistor, a channel area is established between two electrodes called source and drain, and electric charge is generated in the channel area by inserting a gate insulation film between the source and drain, and applying voltage from the gate electrode to pass an electric current between the source and drain. MOS (Metal-Oxide Semiconductor) FET has the gate electrode, gate insulation film and channel, which are made of metal, oxide and semiconductor, respectively. It is one of the most representative semiconductor devices. CMOS (Complementary MOS) has p-type and n-type semiconductors called pMOS and nMOS, and uses the 2 MOSs to form a logic circuit. As MOS FET becomes miniaturized, its channel also becomes smaller. Therefore, it is necessary to generate much electric charge in the channel by thinning the gate insulation film in order to gain a sufficient ON-stage current. However, with SiO_2, which represents the gate insulation film today, when the film thickness becomes below 1nm, a gate leakage current increases due to the film's flaw or electron tunneling. Accordingly, the use of high dielectric constant materials such as SiON and HfO_2 is being studied as materials for gate insulation films that allow generation of sufficient electric charge in the channel and reduce a leakage current.

* 2 Low-dielectric constant (Low-k) insulation film

As LSI speeds up, the time a signal takes to travel through a wiring has become problematic. Therefore, using a low-dielectric constant insulation film in place of SiO_2 for insulation films around wirings is being studied in order to increase the transmission speed of signals. Currently, research is being conducted in organic compound materials and porous materials.

* 3 SOI

When forming LSI on an ordinary Si wafer, it will cause surplus power consumption or decrease speed since the wafer itself has conductivity. SOI (Silicon on Insulator) eliminates the negative impact of the wafer by affixing a thin wafer (0.5 – 100μm) on an insulated substrate made of glass or the likes, or by forming a silicon-oxide insulation film inside the wafer.

* 4 Next-generation lithography

At present, excimer laser (wavelength: 193nm) that uses argon and fluorine gas (ArF) is used as the light source for lithography equipments. Next-generation lithography equipments after the 65nm generation use light sources that emit shorter-wavelength lights in order to increase resolution. Currently, F_2 excimer laser (wavelength: 153nm) using fluorine gas (F_2) in place of ArF, EUV (wavelength: 13nm) using metal gas plasmas, and EPL (variable wavelength) using electron beam with mask projection method are among the major candidates. While each method has an advantage and disadvantage, F_2 has been the prime candidate. Other future technologies include an X-ray lithography equipment (its development has almost halted) and LEEPLE (unlike EPL that uses reduced projection, it is an electron beam lithography equipment that uses equally magnified contact masks, and is being developed by Japanese ventures and backed by NTT and Sony).

* 5 Next-generation memory

The current memories include: SRAM (Static Random Access Memory), which is high-speed and used in processors and cache memories; DRAM (Dynamic RAM), which is relatively fast and used as the main memory; flash memory, which is slightly slow in writing and erasing but is non-volatile (stored data remains even after the power is turned off); and hard disc and optical disc, which are slow but have large capacities, in descending order. The next-generation memory requires such properties as non-volatility, high speed and low power consumption to replace DRAM and the others that follow DRAM. Magnetic memory (MRAM) uses magnetism to store data as with the hard disk. Ferroelectric RAM (FeRAM) uses ferrodielectrics' property that enables electric charge excited by voltage to remain even after the voltage is turned off. Other methods include OUM (under development by Ovonyx, a venture financed by Intel), which uses a phase-changing substance whose electric resistance changes between the crystal and amorphous states.

* 6 MEMS

This stands for Micro-Electro-Mechanical Systems. Each MEMS chip uses a micro-fabrication technology, based on semiconductor manufacturing technologies, to contain movable parts measuring around some nanometers to millimeters, and microcircuits. They are also called "micro machines."

* 7 Selete

This stands for Semiconductor Leading Edge Technologies, Inc. It is a joint research union established in 1996 mainly by Japanese semiconductor manufacturers. At the beginning, the union conducted evaluation and standardization of devices that support 300mm wafers. Currently, it conducts research into semiconductor manufacturing technologies for the 65nm and later generations.

* 8 ASET

This is the abbreviation for the Association of Super-Advanced Electronics Technologies. ASET is a joint research union for semiconductor technologies, consisting of more than 10 semiconductor-related companies in Japan. MIRAI is a joint development project for the 65nm generation conducted by ASET.

* 9 Calcium fluoride lens

Since ordinary glass or quartz cannot be used as lens material for the F_2 excimer laser, which emmits at very short wavelength, a calcium fluoride (CaF_2, also called "fluorite") lens is used instead. However, calcium fluoride has disadvantages such as complex refraction (refraction fluctuates according to the crystal azimuth, which is disadvantageous for a lens), low mechanical strength so causes deformation of lens due to weight of itself.

*10 IMEC

IMEC is an academic-business-government semiconductor research center jointly managed by the Belgian kingdom's Flanders provincial government, 4 universities in the province and semiconductor-related companies.

*11 CEA

This stands for "Commissariat a l'Energie Atomique," the French atomic energy commission.It has the research institute for LSI technologies and nanotechnologies.

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4

Trends in Grid Technology
— Will the Grid technology become the core technology for the next-generation Internet application? —

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4.1 Introduction

Recently, the term “the Grid” has been seen more and more often. Grid technology makes computing resources available as needed, anytime anywhere through networks. They are called “the Grid” by the analogy with the electric power grid on which people can freely use electricity from wall outlets without being aware of generators.

There have been a number of examples that drew attention for their application of Grid technology to achieve outstanding performances. One example is that it enables to get one enormous computing power by using a network of high-performance computers, and another is that it enables to get supercomputer power by gathering the idle time of many PCs via the Internet. The latest research focuses on technologies to share not only computing power but also data storage and large-scale specialized laboratory equipment, which attract attention as an essential research infrastructure especially in “Big Science,” such as high-energy physics and space science. As the Grid is also spotlighted as an effective tool in cross-disciplinary fields generated by the convergence of information technology and biotechnology / nanotechnology, many Grid application projects have started in the U.S. and Europe. It is said that the Grid will change the way of scientific research advancement.

Considering the Grid technology enables to realize one-step higher Internet applications, researchers, engineers, computer manufacturers and software vendors throughout the world are vigorously pushing ahead with researches, standardization and commercialization of Grid technology.

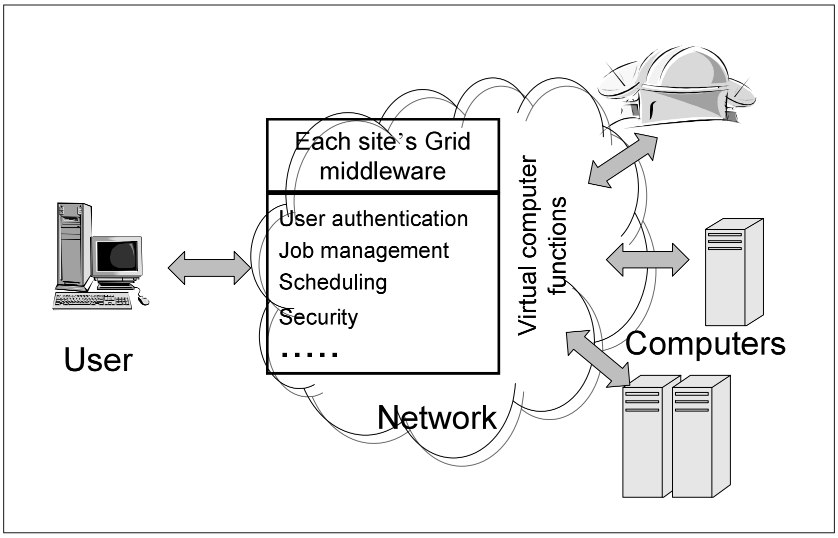
This article outlines noteworthy Grid technology and projects while describing Japan’s strengths and weaknesses in this field, followed by the challenges Japan should address.

“The Grid,” a term coined in supercomputer application technologies, was known as Grid Computing in the early days. As the definition of the Grid expands beyond mere computing, the word has become more inclusive, even referring to application environments in which large data bases and specialized experimental equipment can be shared. Applying a broader definition, these schemes are collectively referred to as “the Grid” in this article.

4.2 Vision of Grid technology

Like the utility model for power supply, the Grid is a concept that intends to provide environments in which computing and information resources are made available to users whenever necessary via networks. More stringently, the Grid is defined as “an environment where diverse computing and information resources (computers, storages, visualization devices, and large-scale experimental equipment) distributed across a network can be used as a single virtual computer by members of a virtual organization.” A conceptual image is shown in Figure 1: computing and information resources can be used via network as a virtual computer for users registered as members of a virtual group formed across real organizations for a certain objective. The virtual computer’s functions are realized through Grid middleware[*1] embedded within computers at each site. This allows users not only to perform any desired computations by

Figure 1: Conceptual image of the Grid



using their own program (computing services), but also to obtain the necessary processed data by using superior programs and data available from other sites (application services).

There are many benefits in creating a Grid. First of all, it provides scientists and engineers with a tool that enables them to efficiently conduct collaborative works from dispersed locations. In the Data Grid, a project funded by the EU, for example, 3,000 high-energy physicists jointly develop data and programs that are shared among them to encourage cooperation and competition of their research activities in order to improve their research efficiency. Since big-science research projects increasingly require massive-scale experimental equipment and data bases and highly intensive computations, sharing research resources is demanded to enhance the efficiency of research activities.

Secondly, Grid technology provides effective use of distributed resources with improved ease of use. For example, the computing power equivalent to a supercomputer can be obtained by gathering idle resources distributed in a network. Very large capability that would not be attainable by a single organization can be shared by connecting distributed resources via network. To take advantage of the high-speed computing capability, however, a high-speed network to ensure fast data transfer is indispensable.

Thirdly, additional benefits are load sharing and improved reliability. Intensive processing loads can be shared over distributed resources to avoid concentrated load on a single computer. This frees each computer from the need to prepare for peak load volume for the system because the overall networked resources complement the necessary capacity. Moreover, a failure in a single computer would not suspend the operation of the entire system, ensuring higher reliability. Even if a certain part of the system is struck by a cyber attack, there is no discontinuity in services, which are supported by the remaining system only with disconnection of the affected part, providing an effective solution to risk management.

Note that the Grid is not a technology to advance a computer itself, but is instead a computer application technology. There are misunderstandings such as the Grid can substitute as a large supercomputer or a large supercomputer can substitute as the Grid. Efforts to raise the performance of supercomputer itself are still needed because there are many computation applications that are significantly inefficient if performed over a network. Improving the performance of individual high-performance computers benefits the Grid gaining larger computation capability.

4.3 History of the research on Grid technology

Grid technology research derives from the studies on remote computing and distributed computing in the 1980's. Driven by the high-speed networks that became available in the 1990's, not only theoretical studies but also building their demonstration systems appeared.

In 1992, Charlie Catlett and Larry Smarr, the National Center for Supercomputing Applications (NCSA), the U.S. published a concept called "metacomputing."[1] They started research in order to realize a virtual computer environment on a network for large-scale parallel computation. In 1995, Tom De Fanti, the University of Illinois, Rick Stevens, the Argonne National Laboratory and others performed the first large-scale metacomputing experiment under the I-Way (Information Wide Area Year) project. In this project, 17 computer centers nationwide were linked together via a high-speed wide-area network for the demonstrations where many applications such as virtual-reality experiments were realized. Originating the I-Way, the Globus Project[2] launched by Ian Foster, Argonne National Laboratory and Carl Kesselman, the University of Southern California in 1996. They developed the middleware for high-performance distributed computing, followed by the 1998's publication of the blueprint describing the concept of "Grid technology."[3] The Gird was defined as "an environment in which users can use computing resources as needed at anytime without being aware of the location of the computers."

The Globus Toolkit, the software developed in the Globus Project, offers basic Grid middleware capabilities such as user authentication and Grid resources management. The software, which is made available by Argonne National Laboratory as open source, has been utilized in so many research projects for Grid constructions that it has become the de facto standard. Building a Grid system, however, requires the development of a number of programs in addition to the Globus Toolkit, which provides only the basic functions.

There is another direction of research aiming to make good use of idle CPUs through the Internet. In 1985, Miron Livny, the University of Wisconsin proposed an idea of utilizing distributed workstations' idle CPUs for computations. In 1991, he succeeded in gathering the equivalent of 400 CPUs in a project known as Condor. In 1997, Scott Kurowski established Entropia, Inc., and in two years latter successfully collecting the computing power of idle PCs through the Internet could provide Tera*2 flops level computation, which is almost equivalent to the highest level of performance delivered by a supercomputer of that time.

Metacomputing and the utilization of idle processing power, both of which provide virtual single computer environment through networks by distributed computers, are component technologies of the Grid.

In Japan, meanwhile, research on global computing, a technology to allow people to operate computers from remote places, is in progress. One of the activities toward this end is Ninf (Network Infrastructure for Global Computing), a project launched in 1994 by Satoshi Sekiguchi, the Electrotechnical Laboratory (currently known as the National Institute of Advanced Industrial Science and Technology), Satoshi Matsuoka, the Tokyo Institute of Technology and others. As global computing research, they worked on the design and experimental proof of Remote Procedure Call (RPC), protocols between clients and servers enabling that clients make servers in the network perform computations. The project's outcomes are now under review for standardization as part of Grid middleware. Researchers involved in Ninf are now collaborating with the participants of NetSolve, a similar independent initiative of the University of Tennessee, to make further advances in research and development. In addition, the Japan Atomic Energy Research Institute, the Institute of Physical and Chemical Research, and computer centers at universities have contributed to the studies on technologies to enable the remote or shared use of supercomputers via networks. These activities have led to the creation of the essential basis for the development of Grid technology.

4.4 The background of the emergence of the Grid

Major driving forces for the recent considerable development of the Grid are the growth of the seeds of technology and the rise of needs of applications. In technology developments, the latest Internet backbone networks provide 10-Gbps level for domestic access and 1-Gbps level for international access, ushering in the so-called broadband age. Furthermore, network speeds and reliability that have been improved along with the growing the Internet allows the Grid to provide easy-to-use computing environment for distributed computers via the Internet.

In the domain of application needs, the Grid is beginning to be viewed as an indispensable research tool for IT-driven activities in science, such as biotechnology and nanotechnology represented by e-Science.*3 On the other hand, big science such as high-energy physics and space science intends to improve research efficiency by sharing expensive specialized laboratory equipment and data analyses, positioning the Grid as an infrastructure for research activities.

4.5 Applications of the Grid

Among the variety of possible applications of the Grid, typical examples expected in the future are described below.

(A) Metacomputing

Performing large-scale computations that are impossible on a single supercomputer by simultaneously running multiple high-performance computers (HPC) such as supercomputers distributed across a network. The intent is to create a virtual enormous computer. There are two possible types of computations performed on the Grid: single-program computations that are divided and distributed to parallel computers; and computations for which the same program is installed onto multiple computers so that each computer is given a different set of data in parallel processing with collecting the results at each computer (parameter sweep). Since data transfer rates on networks are slower than those inside a computer on the order of magnitude, computations performed on the Grid should be of a small data access range, or so-called small grain computations, to make the most of its capabilities.

(B) Research Grids (Virtual Laboratories)

Building a community of researchers and research institutions, each participant can access community's resources of computers, databases, and experimental equipment through networks. In addition to using each other's data, this scheme allows researchers to couple their application programs with those of others to perform complex simulations.

In conventional remote access, each site had its own software. The Grid provides common interfaces for remote access enabling broader connectivity and easy-to-build.

Research Grid activities in the U.S. include, as shown in Table 1-1, Grid Physics Network in high-energy physics, Fusion Grid in nuclear fusion, the National Virtual Observatory for astronomical observation, the Earth System Grid in meteorology, and the Biomedical Informatics Research Network (BIRN) in bioinformatics, which are also seen in Europe through similar projects.

(C) Access Grids

Access Grids provide an environment that facilitates smooth and speedy operation of joint research projects by enabling remote researchers to share the same screen views and computational results. In addition to an image quality better than TV conference systems through multicasting via high-speed networks, Access Grids offer tools such as file sharing for efficiently conducting collaborative work.

(D) Data Grids

Also known as Data Intensive Computing, Data Grids allow network-based remote access to data that is too large to be stored in a single location or data that is distributed to physically separate locations. The technology is still under study with such themes as efficient storage and readout of large data sets, and high-capacity Internet communications. The key here is the data transfer time. Since the transmission of large volumes of data takes a considerable time even over a super-high-speed network, primary analyses and calculations need to be performed on the site of data generation.

In an experimental project on a huge accelerator at the CERN (European Organization for Nuclear Research), for example, 7,000 researchers from 500 institutions perform several hundred million times of experiments annually with producing 6-8 petabytes of data. In order to analyze such experimental data on high-energy physics and to share the results among researchers, the Grids are under development in projects such as the EU Data Grid in Europe and the Grid Physics Network (GriPhyN) in the U.S. Grid technology is also used for the space research to describe the entire universe based on the data obtained from more than one space observatory. Thus, Data Grids improve the efficiency of activities in big science.

(E) Computer Service Grids

Providing as much computing power as needed on an on-demand basis without the users being aware of the type of computation server, by a Grid having multiple computation servers on the network within an organization. A Computer

Table 1-1: Major Grid projects in the U.S.

Project	Participants	Budget	Term	Objective
PACI National Technology Grid	NCSA, SDSC	NSF	1998~	Dissemination of Globus and creation of a computational grid to support dispersed laboratories
Information Power Grid	NASA	NASA ($7-8M for application, excluding infrastructure)	1999~	Implementation and visualization of multi-disciplinary simulations on a heterogeneous distributed computing system
Access Grid	ANL, LBNL, LANL, NCAR, NCSA, etc.	DOE,NSF $2M/Y	1999~	Development and deployment of Grid-based remote conferencing systems and other collaboration systems. Part of the outcome was used to broadcast GGF meetings to Access Grid members.
ASCI Grid (DISCOM)	Sandia NL, LLNL, LANL	DOE	1999~	Application of ASCI to the Grid, Security development
Grid Physics Network (GriPhyN)	ANL, U of Florida, Fermi Lab, etc.	NSF $12M/5Y	2000~	Sharing data in high-energy physics and astronomy
Particle Physics Data Grid(PPDG)	ANL, LBNL, Caltech, SDSC, etc.	DOE $9M/3Y	2000~	Sharing data in particle physics
Tera Grid	NCSA, SDSC, ANL, Caltech	NSF $12M@2001, $53M@2002	2001~	Construction of "One Peta byte Gateway": 13.6TF, 6.8TB of memory, 79TB built-in hard drive, 576TB network-aggregated hard drive
International Virtual-Data Grid Lab (iVDGL)	U of Florida, U of Chicago, Indiana U, Caltech, Johns Hopkins U, etc.	NSF $13.7M/5Y	2001~	Linking of US, European and Japanese Data Grids for technical development and expansion of the Data Grid
Network for Earthquake Eng. Simulation Grid(NEES)	U of Southern California, U of Michigan, ANL, NCSA, etc.	NSF $10M/3Y	2001~	Earthquake simulations
National Virtual Observatory (NVO)	Johns Hopkins U, Caltech,etc.	NSF $10M		Virtual space observatory
Grid (Grid Research Integration Deployment and Support) Center	U of Chicago, U of Southern California, U of Illinois, U of Wisconsin, etc.	NSF $12M	2001~	Integration of Grid software and deployment and support for Grid platform software
DOE Science Grid	DOE			The generic name for DOE's scientific Grids; Dissemination and deployment of the Grid; Development of support tools for researchers
Fusion Grid	ANL, LBNL, Princeton Plasma Physics Lab, General Atomics, MIT, etc.	DOE $6M/3Y	2001~	Grid for nuclear fusion research
Earth Systems Grid	ANL, LLNL, NCAR, etc.	DOE $5M/3Y		Grid for meteorological research
Biomedical Informatics Research Network		NIH $20M	2002~ 2006	To develop technologies for visualization of the brain and the neural system and to share databases

ANL=Argonne National Lab, LANL=Los Alamos National Lab, LBNL=Lawrence Berkeley National Lab, LLNL= Lawrence Livermore National Lab, NCSA=National Center for Supercomputing Applications, SDSC=San Diego Supercomputer Center, NCAR=National Center for Atomospheric Research

Source: Author's compilation from relevant web sites.

Service Grid works like a virtual computer center. An example is the Campus Grid of the Tokyo Institute of Technology. It consists of PC clusters (a total of approximately 800 processors) distributed campus-wide and 25 terabytes of storage that are both accessible via the high-speed campus network. Another example is seen in the private sector, where companies have constructed Computer Service Grids by connecting their computer centers through their Intranets.

While the commercialization of Computer Service Grids is under discussion as an extension of this technology, there remain problems such as pricing and security. Therefore, current applications are limited to closed networks built on campus or corporate Intranets.

(F) Grid ASPs (Application Service Providers)

Grid ASPs offer services in which remote users send data through a network to be run on application programs operating on a high-performance computer, and receive the results. While Computer Service Grids mentioned before require users to make programs by themselves, users of Grid ASPs can make use of ready-to-run programs with proven functionality. Another potential service is to provide useful databases such as genome data to Grid ASP users. With the Grid, medical data that may not be exposed for privacy protection, for example, could be made available on the limited condition that the data is processed within the site of the database provider by using a desired analytical program so that only the results are sent out to the Grid ASP users.

(G) Desktop Grid Computing

Being aware that home-use PCs sit idle most of the time, this scheme intends to gather the untapped computing power of these PCs in order to perform certain computations. It is also known as Volunteer Computing as participants usually offer their idle computing power for free.

The technology has been applied for space observation data analysis (SETI@home: Search for Extraterrestrial Intelligence at Home) and for the development of new drugs to cure cancer, AIDS and leukemia (Parabon's Compute-against-Cancer, Entropia's Fight AIDS At Home, United Devices' Cancer Research Project, and Intel's Philanthropic Peer-to-Peer Program). In the case of SETI@home, four million volunteers offer their PCs' idle time to achieve the computing power equivalent to a 40-TeraFlop supercomputer.

In Desktop Grid Computing, only limited types of computations are possible because the processing power of each participating computer is not high enough and these computers are linked via slow networks. Parameter sweep applications that execute the same process on large volumes of different input parameters, are ideal for this type of Grids. It is necessary for the Grid to have software upgrades, security, privacy protection and fault tolerance (ability to resume in case of failure).

Recently, some companies have built systems for order/purchase management by using the idle computing power of their PCs. In their cases, as the PCs are connected to their own Intranets, there is no need for concern about security and fees.

(H) Sensor Grids

A Sensor Grid is one of the ultimate form of the Grid in ubiquitous computing in the future. Many Sensors installed everywhere are connected to the Internet to allow access to data from any place. A possible application is the monitoring of the global environment by collecting and analyzing data obtained from numerous sensors positioned all over the world including remote places.

4.6. Grid projects

Based on the awareness that the Grid not only serves as a critical infrastructure for the advances of big science, but also provides an indispensable basis for the convergence of IT and biotechnology / nanotechnology, the U.S. and European countries are actively conducting national projects on the Grid. The following sections describe the activities in the U.S., Europe and Asia, which are listed in Table 1-1 to 1-5.

(A) U.S. projects

Since Grid technology originates from a study in the U.S. at the use of supercomputers via a network, the U.S. already has an ample accumulation of resources from the years of

Table 1-2: Major Grid projects in Europe

Poject	Participants	Budget	Term	Objective
Grid in 6th Framework Program		EC 300 M Euro/5Y	2003-2007	FP6 covers IT, biotech, nanotech, astronomy, food, environment, energy, and intelligent society. Grid construction is planned in each area with a total investment of 300M Euro.
EU Data Grid	CERN, U of Heidelberg, IBM UK, CNRS, INFN, PPARC, SARA, etc.	EC 9.8 M Euro/3Y	2001-2003	Development for realtime execution of petabyte data processing via Grid network
EuroGrid	Forschungszentrum, Pallas GmbH, U of Bergen, CNRS, Warsaw U, U of Manchester, ETH Zurich, etc.	EC	2001-2003	Grid applications development: molecular biological modeling, meteorological forecasting, CAE simulations, and Grid middleware development
GRIP (Grid Interoperability Project)	U of Southampton, Deutcher Wetterdienst, U of Manchester,, Pallas GmbH, U of Warsaw U, etc.	EC	2002-2003	Building up compatibility between UNICORE and GLOBUS
MAMMOGRID	U of West England, U of Pisa, U of Oxford, U of Cambridge, Mirada Solutions, etc.	EC	2002-2005	Development of Mammogram database for healthcare research

Table 1-3: Major Grid projects in the U.K.

Project	Participants	Budget	Term	Objective
eScience		£120M/3Y	2001-2004	The umbrella program to promote scientific research with Grid development. £75M of the budget is for Grid applications development.
Grid Particle Physics	Universities of Birmingham, Bristol, Cambridge, Edingburgh, Glasgow, Lancaster, Liverpool, Manchester, Oxford,Sheffield, Sussex, Imperial College, CERN, etc.	DTI PPARC £17M/3Y		Particle physics research jointly conducted by EU DataGrid(CERN), US GriPhyN and PPGrid
Astro Grid	Universitiies of Edinburgh, Leicester, Cambridge, Queens Belfast, etc.	DTI PPARC £5M	2001-2004	Astronomical observation and research jointly conducted by EU AVO and US NVO.
DAME (Distributed Aircraft maintenance Environment)	Universitiies of York, Oxford, Sheffiled, Leeds, etc.	DTI EPSRC £3M	2002-2004	Sharing of aeronautical data and engine data for aircraft maintenance
Reality Grid	Universitiies of London, Manchester, Edinburgh, Loughborough, Oxford, etc.	DTI EPSRC £3M		Tools for materials research
myGrid	Universitiies of Manchester, Southampton, Nottingham, Newcastle, Sheffiled, etc.	DTI EPSRC £3M	2001-	Creation of environments in which biological and other data are made accessible to medical doctors as well as to IT engineers
Biology, Mediacal, Environmental Sciene	Under consideration	DTI £23M		Grid in biology, medical and environmental science fields

DTI=Dep. of Trade and Industry, PPARC=Particle Physics and Astronomy Research Council, EPSRC=Engineering and Physical Sciences Research Council, NERC=Natural Environment Research Council

Source: Author's compilation from relevant web sites.

Table 1-4: Major Grid projects in Japan

Project	Participants	Budget	Term	Objective
IT Based Laboratory (ITBL)	Japan Atomic Energy Research Institute, Institute of Physical and Chemical Research Japan, etc.	MEXT ¥5B ¥5.2B@2000 ¥2.7B@2001	2001-	Creation of a virtual research laboratory environment by linking supercomputers via Super SINET
Research funded by Grant-in-Aid for Scientific Research on Priority Areas “Informatics” A05Grid	Osaka U., Tokyo Institute of Technology, National Astronomical Observatory Japan, etc.	MEXT ¥0.8B /5Y	2001-2005	Medical Grid by Osaka U.’s Shimojo Group, P2P Data Grid by TITech’s Matsuoka Group, Nationa Astronomical Observatory Japan, etc.
TITech Campus Grid	Tokyo Institute of Technology	FY2001’s supplementary budget ¥0.2B	2001	Construction of a Grid on the campus
BioGrid Center, Osaka U.	Osaka U.	FY2001’s supplementary budget ¥0.2B	2001	Construction of a Grid infrastructure
e-Science project “Construction of a supercomputer network”	Osaka U., etc.	MEXT ¥0.55B @2002	2002-2006	Development of technology to link large-scale Data Grids and Computing Grids
Development of network computing technology “Grid Cluster Federation”	National Institute of Advanced Industrial Science and Technology, Tokyo Institute of Technology, U. of Tsukuba, U. of Tokyo	METI 1.3B/5Y	2002-2006	Realization of cluster technology, Grid technology and 10-petabyte-level massive data processing
National Research Grid Initiative (NAREGI)	Under consideration	MEXT (under consideration)	2003-2007	Creation of the world's highest level Grid environment to promote interdisciplinary research through a marriage of biotech / nanotech with IT
Grid computer “Business Grid Computing”	Under consideration	METI (under consideration)	2003-2005	Development of software that provides flexible services by using numerous networked computers/storage systems like a single computer

Source: Author's compilation from relevant web sites

Table 1-5: Major Grid projects in South Korea and China

Project	Participants	Budget	Term	Objective
Korea Grid Initiative	Led by the Korea Institute of Science and Technology Information (KISTI)	¥4.3B/Korean Ministry of Information & Communication (not including Network)	2002~2006	Development of Grid Middleware; Data Access; Applications development (over half of the budget is for applications development)
China Computational Grid	Chinese Academy of Science	$40M/Ministry of Science and Technology		Connection of 10 HPC centers via Network; One of applications is Genomic Aapplications.

Source: Author's compilation from relevant web sites

developing Grid technology and of Grid demonstration systems. The nation continues in its vigorous activities for further promoting the development of Grid technology, large-scale demonstration systems and Grid applications.

In the NSF’s TeraGrid project, as one example, research on processing large volumes of data on the order of terabytes is in progress. Four computing centers nationwide are constructing a large-scale integrated demonstration system in which high-performance computers with a combined processing capacity of 13.6 teraflops and an enormous storage space of 576 terabytes are planned to be connected to a 40-Gbps high-speed network. Another noteworthy initiative is NIH’s Biomedical Informatics Research Network (BIRN). Through this project, 10 medical research institutions nationwide, with the University of California, San Diego as the leader, are involved in the development of a Grid to visualize the activities of the brain and to share the acquired data, in order to study Alzheimer and other diseases. A large number of researchers, including medical science and medical care, participate in the program.

Meanwhile, since the September 11 terrorist attacks, the U.S. government has been discussing measures to tighten homeland security, of which the defense against cyber terrorism is a key element. From this point of view, security of their Grid projects is being reviewed, giving higher priority to security issues in the Grid world.

(B) U.K. and European projects

In the U.K., a program known as e-Science was launched in 2000. The program's intent is to encourage and accelerate scientific research activities by using IT. Specifically, the government is actively promoting Grid-enabled projects that pursue the sharing of expensive computers, laboratory equipment and large data sets distributed worldwide. As the nation's Grid infrastructure, they have established nine National e-Science Centers nationwide and they are building the Grid by connecting high-performance computers at via a high-speed network. Applications developed on this Grid range from high-energy physics, genomics, biotechnology, protein structure analysis , medicine and health to environment, meteorology, astronomy, chemistry and materials. Dr. John Taylor, Director General of the Research Councils OST UK, who leads the e-Science program, says that the Grid is a necessary infrastructure for the U.K. to participate in global scientific research activities.

Even without the presence of domestic supercomputer makers, European countries have the accumulated expertise in the application of supercomputers and have started activities toward Grid applications early. EU's representative project is the EU Data Grid, which is designed to handle large-scale data.The project, led by CERN, has been carried out in collaboration with the U.S. and Japan.

Since the EU-funded projects must be based on joint development of more than one EU member nation, Grid projects, which usually aim at the construction of a common research infrastructure, fit very much in the purpose of the EU project. Other ongoing European efforts for Grid projects except for those in the U.K. include Unicore in Germany, INFN Grid (Italian National Institute for Research in Nuclear Physics) in Italy, and Grid-based Virtual Laboratory Amsterdam (VLAM) in the Netherlands.

(C) Japanese projects

In IT-Based Laboratory (ITBL), a project started in 2001 that seeks to construct a virtual laboratory, the Japan Atomic Research Institute, the Institute of Physical and Chemical Research and others are involved in building a common research environment by supercomputers via a communication network. By fiscal 2001's supplementary budget fund, more Grid-oriented projects have been launched such as the establishment of Grid Research Center in National Institute of Advanced Industrial Science and Technology, and the construction of Tokyo Institute of Technology's Campus Grid. In fiscal 2002, the BioGrid Project led by Osaka University commenced, and the construction of the Grid for bioinformatics has started by the University of Tokyo, Japan Advanced Institute of Industrial Science and Technology, the University of Tokushima, the Institute of Physical and Chemical Research and others as part of the "Genomic Information Science" research project supported by the grant-in-aid for the scientific research. Furthermore, in fiscal 2003, full-scale Grid construction activities such as the National Research Grid Initiative, an effort toward the creation of the world's highest-level Grid, and the Business Grid Project, an attempt to develop software applications that enable flexible Grid services, are planned.

In addition, Super SINET, a project launched in 2000 and serving a high-speed network connecting computer centers at universities and national laboratories, is now an essential infrastructure for Grid construction

(D) Asian projects

In the Asian region, major countries that are conducting Grid research are South Korea, China, Taiwan and Singapore. Japan takes the initiative in regional Grid promotion through Asia-Pacific Grid (APGrid) and the Pacific-Rim Application & Grid-Middleware Assembly (PRAGMA), promotional organizations for Grid activities in the Asia-Pacific region including the U.S. and Australia. In addition, a high-speed network infrastructure for the Grid is being built through the activities of Asia-Pacific Advanced Network (APAN). These successful efforts have allowed Asia to secure a position as one of the world's three poles in the Global Grid Forum (GGF), a global standardization organization for the Grids. Asian nations are actively launching Grid projects to promote fast catch-up. Japan must make further progress to stay ahead of them.

(E) Challenges in Japanese projects

Projects in the U.S. and Europe place emphasis on the development of Grid applications as well as Grid technology. For applications development, cross-disciplinary collaboration between IT and biotechnology / nanotechnology is important. While it has been seemingly rare in Japan for researchers to actively participate in research in foreign fields, IT engineers are now asked to jump into Grid application areas to create software required in each of application areas.

There are many pieces of software born at universities in the U.S. and Europe. As this is also the case with the Grid, a number of Grid software ventures have already been spun out from universities. Based on the Legion project, launched at the University of Virginia in 1993, Prof. Andrew Grimshow established a company named Applied MetaComputing (now known as AVAKI) to commercialize the Legion's Grid technology.

On the other hand, in Japanese projects many pieces of software have been developed however there were very rare cases of commercialization based on result of projects by universities. The reason is that as projects at universities cannot afford many engineers, what they can do is limited to the development of a core program and the demonstration system which shows only essential component functions. Commercialization of their software requires a larger number of engineers to proof their functions by larger-scale experiments and to add peripheral programs for such as application interface.

In the projects at U.S. universities, which are enabled to employ more research engineers, larger-scale demonstrations are performed. The U.S. government often demands project members not only to conduct basic research but also to verify the practicability of the outcomes. Researchers who have been involved in such projects are given options such as establishing a venture business or participating in another project when the project ends. In Japan, where until fairly recently universities could not employ staff specifically for their projects, a lack of job mobility among research engineers and personnel shortfalls remain unchanged. How to handle intellectual property rights at universities is still in a transitional stage, although systems for this end are being established.

It is hoped that many pieces of software are created based on the results of large-scale projects at Japanese universities. In the U.S. and Europe, projects at universities are the birthplace of many innovative software applications, indicating that universities are the foundation of the nation's technical capabilities in the software field. In order to enhance Japan's technical strength in software development, expanding the capability of Japanese universities to create software systems and increasing their accumulation of technical expertise are essential.

4.7 Trends in standardization

Since worldwide connectivity is the key to taking advantage of the Grid, how to standardize its interface is very important issue in the Grid communities.

Activities for Grid standardization started with the formation of the Grid Forum (GF) consisting of researchers involved in Grid projects in late 1998. Subsequently, the European Grid Forum (E-Grid) and the Asia-Pacific Grid Forum (AP-Grid) were founded in Europe and Asia-Pacific respectively, with a view to promoting regional Grid development. In 2001, GF merged with the standardization groups in E-Grid and AP-Grid, resulting in the establishment of a global standardization organization known as the Global Grid Forum (GGF). With two Japanese members taking part in the Steering Group and one in the external advisory committee, Japan has shown its presence in the Grid community.

GGF adopts the same standardization process as the IETF (Internet Engineering Task Force), a

Table 2: List of groups organized for the Global Grid Forum

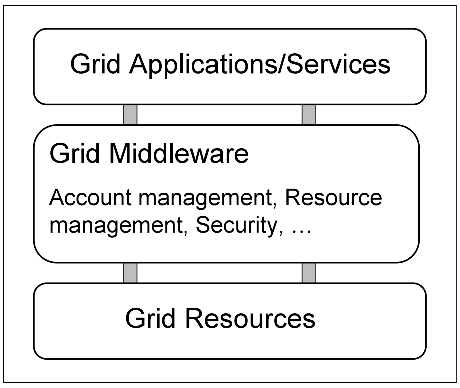
Area	Working Groups	Research Groups
Applications and Programming Environments		— Advanced Collaborative Environments (ACE-RG) — Advanced Programming Models (APM-RG) — Applications and Test Beds (APPS-RG) — Grid Computing Environments (GCE-RG) — Grid User Services (GUS-RG)
Architecture	— Open Grid Service Infrastructure (OGSI) — Open Source Software (OSS) — New Productivity Initiative (NPI)	— Grid Protocol Architecture (GPA) — Accounting Models (ACCT) — Service Management Frameworks (JINI)
Data	— GridFTP — Data Access and Integration Services (DAIS)	— Data Replication (REPL) — Persistent Archives (PA) — Grid High-Performance Networking
Information Systems and Performance	— Discovery and Monitoring Event Description (DAMED) — Network Measurement (NM) — Proposed: Grid Information Retrieval (GIR) — Proposed: CIM based Grid Schema	— Relational Grid Information Services (RGIS) — Grid Benchmarking (GB)
Peer-to-Peer	— NAT/Firewall — Taxonomy/Nomenclature — P2P Security — File Services — Instant Messaging Interoperability	
Scheduling and Resource Management	— Grid Resource Allocation Agreement Protocol (GRAAP) — Management Application API Working Group (DRMAA) — Scheduling Dictionary (DICT) — Scheduler Attributes (SA)	
Security	— Grid Security Infrastructure (GSI) — Grid Certificate Policy (GCP) — Open Grid Service Architecture Security (OGSA-SEC)	— Kerberos

Source: Web site of the Global Grid Forum at http://www.gridforum.org/L_WG/wg.htm

standardization group for the Internet. In other words, research groups and working groups in GGF are organized for each technology to discuss the relevant issues with clear objectives and goals. Each group will be dissolved when its mission is completed. At present, GGF has 21 working groups and 14 research groups in seven areas as shown in Table 2. Group members hold discussions through group meetings and exchange opinions via e-mail, in addition to the general meetings held three times a year, allowing speedy progress of the standardization discussions. For those who are abroad, keeping up with their activities requires considerable effort. The results of GGF have become the de facto standards in the field, but are not de jure or enforced rules.

The focus of Grid standardization activities so far has been Grid middleware as shown in Figure 2, which serves as common system software across application fields. Grid communities are competing to take the initiative in setting up an interface with higher-layer applications or with lower-layer Grid resources. As Grid technology covers a wide range of functions, dominance by a single software package or a new middleware package is unlikely. Therefore, Japan or any single company has no chance of attaining supremacy in standardization using its particular idea. Instead,

Figure 2: Layers of Grid system



Japan can contribute to the standardization by playing a complementary role in worldwide collaborative activities to advance superior technologies.

In June 2002, the Grid Consortium Japan was founded aiming at conducting the development and standardization of Grid technology under the coordination of standardization activities as well as the promotion of Grid technology and the exchange of its information. As the development from standardization to commercialization usually takes very short time in the field of Internet software, the activities in the standardization organizations must be carefully monitored.

4.8 Challenges to Grid technology

With Globus Toolkit and other types of middleware available, many projects today focus on the construction of Grids or the development of applications to run on the created Grids. However, the available software still falls short of enabling researchers to easily build Grid-based systems. Current Grid technology imposes a variety of restrictions that researchers intend to remove through their efforts.

Current challenging research themes include security control across different organizations, alignment of policies for operation, pricing schemes, actions at failure, ensured communication channels by QoS (Quality of Service), dynamic resource management, and large-scale data processing. More specifically, research subjects expected for the next three to five years are: security control between firewalls protecting from foreign access and Grid-enabled access from other organizations, large-scale data transfer in which a broadband communications channel must be secured through QoS control, dynamic resource management through the constant monitoring of online resources, resolution of the contradiction between computer operating policies that vary from organization to organization to provide an integrated operating policy for Grid users, and systems to charge fees for external access.

4.9 Recent trends among makers in Japan and elsewhere

Construction of the Grid requires high-performance computers and high-speed networks for the hardware infrastructure. In the U.S., active participants in the development of the Grid are IBM, Sun Microsystems and Hewlett-Packard (including former Compaq), with Microsoft giving attention to Grid middleware.

In March 2002, IBM proposed applying the standards for Web services to Grid middleware, an idea having been approved by GGF. This has quickly raised high hopes for advances in the commercialization of Grid technology, the scheme of the proposal suggests new approach for integration with e-commerce platforms. Thus IBM, in addition to the sales of high-performance computers for the hardware infrastructure, has been making considerable efforts for the dissemination of Grid middleware, the software products they are actively developing.

In Europe, where there is no computer manufacturer, hardware used for Grid construction consists of computers made by mainly U.S. makers. Accordingly, business activities toward the development of Grid applications are jointly conducted with U.S. counterparts.

When looking at the Asian region not including Japan, significant efforts to build Grids are being made there as well. With a recent leap in the performance of PC clusters and high-performance computation servers, the construction of a Grid is now relatively easy by deploying US-made computers.

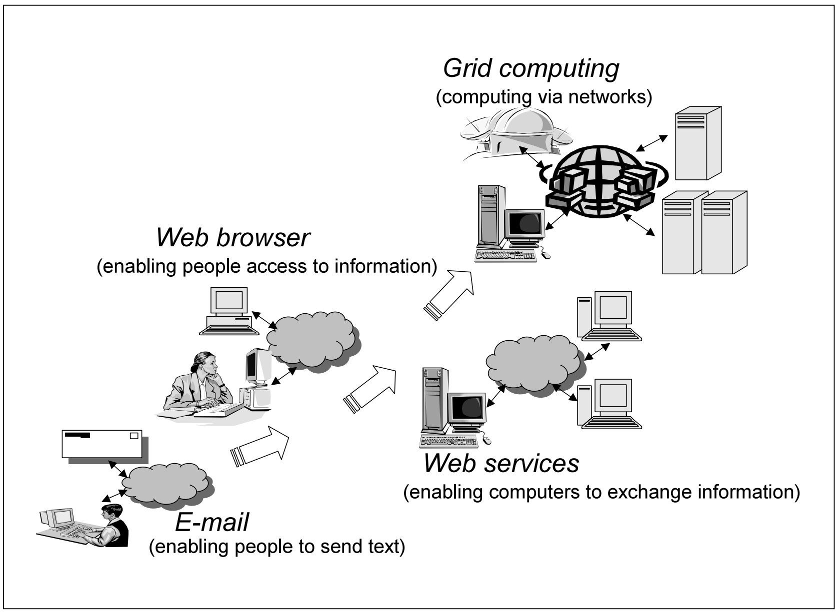
Meanwhile, Japanese computer makers, which are behind U.S. counterparts in the area of Grid development, are struggling to catch up.

4.10 Positioning Grid technology

Grid technology, as one of the Internet application technologies, appears to have the potential for significant growth when taking into account how Internet technology has evolved. The history of the development is shown in Figure 3.

Application of the Internet started with e-mail, a

Figure 3: Development of Internet applications



technology to exchange messages via networks. Once Web browsers appeared as a tool to view information on remote sites, their convenience led to the explosive expansion throughout the world. The growth was attributable to the advantage that Web browsers enable users to view information regardless of the types of terminal devices or operating systems they use. With its expanded availability and enhanced reliability, the Internet has become a common tool for a range of business operations.

Following the phase in which only humans could browse online information, Web services technology emerged and enabled computers to automatically retrieve and interchange information through a wider range of interaction with other computers. Web services have also changed the way of data exchange between computers, a technology known as EDI (Electric Data Interchange), by allowing data exchange over the Internet as an open network instead of the conventional methods based on platform-specific rules. The technology is expected to facilitate safe e-commerce and Business-to-Business transactions.

The Grid can be considered as an extension of Web services technology. While Web services enable access to data and information available on the Internet, the Grid allows the use of computing resources such as computers, databases and laboratory equipment connected to the Internet.

4.11 The future of the Grid and expected challenges

(1) Significance of the Grid

Grid technology enabling computer resources on a network to act a virtual single computer with improved ease of use, is expected to become the core technology in next-generation Internet applications. The Grid also provides a valuable research infrastructure for many fields by enabling the remote use of expensive computers, large-scale data, useful analytical programs, and high-cost experimental equipment. For example, in big science such as high-energy physics and space science, the sharing of high-cost computers, expensive laboratory equipment, and remote facilities can result in improved research efficiency. The Grid can also benefit cross-disciplinary research fields created by the convergence of information technology and biotechnology/nanotechnology, where data and analytical programs can be jointly developed and shared, promoting collaboration in research. The Grid will become an essential element of the research infrastructure in fundamental science, with the potential of changing the conventional styles of research.

The Grid thus can possibly encourage joint research projects, and a growth in joint activities in interdisciplinary areas may lead to the creation of new fields of study. Traditionally, the majority of

Japanese research activities were self-contained due to barriers that divided each research field and inhibited interdisciplinary cooperation between researchers from different domains. The promotion of such collaborative initiatives is another advantage of the Grid's construction.

(2) Toward the development of Grid technology

Born in the U.S., the concept of the Grid has developed mainly in the country of its origin. Europe, the region with no computer makers, has been deploying U.S.-made high-performance computers to actively develop Grid applications in collaboration with U.S. research institutions. On the other hand, fortunately, Japan has leading research expertise in Grid technology together with domestic computer manufacturers, an environment that allows the creation of prominent technologies through Grid projects jointly conducted by universities, national research laboratories and computer makers. Given that homeland security has been reinforced in the U.S. since the September 11 terrorist attacks, security must be considered as a critical factor in the development of Grid technology.

Standardization is another key issue in Grid technology development, as they act as Internet-enabled software. Grid technology is to be standardized through international collaboration aiming to create superior technologies, rather than through the dominance by a single company or nation with its particularity. In such a situation, Japan has to come up with outstanding schemes if it hopes to have its proposals adopted as standards. To get Japan's technological presence in next-generation Internet application technologies, we should offer a large number of prominent technologies and contribute to the standardization of the Grid. Making the most of its Grid projects aimed at developing Grid technology, Japan must promote its technologies in the U.S.-dominated Internet world.

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Glossary

*1 middleware

Software that functions as an intermediate layer between operating system software and application software. While not including operating system software, middleware provides basic functions that are shared among many applications.

*2 tera

The 12th power of 10, or trillion. A thousand times greater than giga.

*3 e-Science

Applying IT to encourage and accelerate scientific research. It can also indicate the fields of study where IT is intensely exploited to promote research. IT, including the Internet, high-performance computers and the Grid, does not only serve as a research tool but also creates new research field such as bioinformatics. Although "e-Science" is the name of a famous UK project, it often also refers to the concept the project aims at.

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5

Trends in the Studies of Heat Island Mitigation Technology — Analysis from the Viewpoint of Energy Use —

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5.1 Energy use and urban problems

Careful considerations of urban economic development and environmental issues arouse concerns that extreme urbanization may hamper the growth of a city and deteriorate the environment. The heat "island effect" is a phenomenon where aboveground temperatures in a city become higher than those in its suburb. A situation in which all the city dwellers depend on air conditioners to sleep on sultry nights is undesirable for the urban environment. In addition, it is pointed out that the concentration of air pollutants above the city and considered localized torrential rainfall are partly due to the heat island phenomenon[1] .

The pattern of energy use (electricity, oil, gas, etc.) in Japan indicates that a large part of energy is being consumed in the city. Consumed or used energy is eventually converted to heat, most of which is released into the air. In this sense, the heat island phenomenon can be considered as a typical example of environmental issues related to energy use – i.e., the introduction of energy into the city and its consumption. It is thus very important to discuss the heat island effect from the viewpoint of energy.

Chapter 5.2 of this article provides an overview of the heat island effect; Chapter 5.3 introduces mitigation measures such as the interception and discharge of heat energy; Chapter 5.4 addresses the impact assessment of urban waste heat associated with the introduction of cogeneration systems; and Chapter 5.5 provides a summary of the heat island phenomenon from the viewpoint of energy use, while suggesting another viewpoint that is needed for studying heat island mitigation measures in the future.

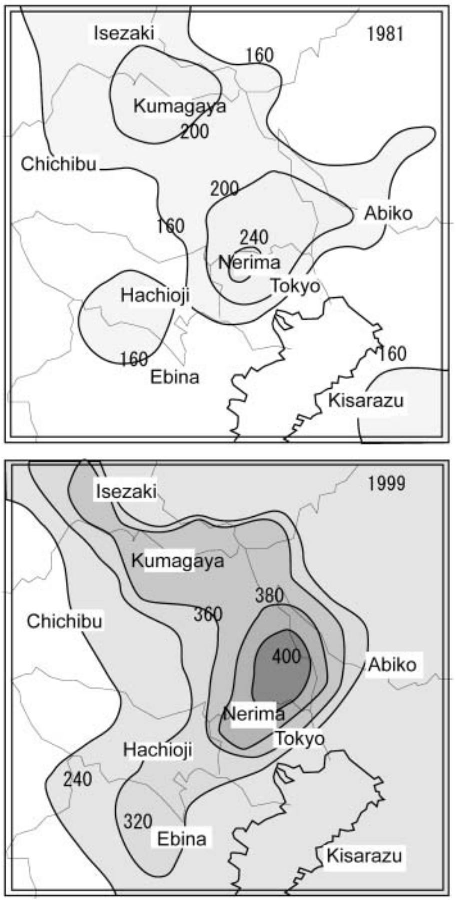
5.2 The present state of the heat island

5.2.1 *The present state of the heat island phenomenon*

The heat island was considered to be a phenomenon limited to large cities like Tokyo and Osaka. This problem, however, is now emerging in local cities such as Fukushima (population: 290,000), Shizuoka (470,000), Hikone (110,000) and Kumamoto (660,000) [2]. Specifically, periods with temperatures above 30 °C are becoming longer and sultry nights are on the rise in all of these cities. Higher temperatures in the summer months boost demand for air conditioning, thereby increasing power consumption. And higher operating rates of thermal plants to meet the increasing power demand will lead to additional CO_2 emissions. For this reason, the heat island effect is by no means a localized problem attributable to the activities of each citizen. Rather, it is a global problem.

The distribution of temperatures in large cities like Tokyo and Osaka can be represented in a contour form, the center of which exhibits the highest temperature. The term "heat island" derives from the shape of this contour form, which looks like the map of an island. Various observations indicate that the recent unusually hot summers in large cities are not due to climate changes associated with global warming. For instance, the annual average temperature in Tokyo has increased by some 2 °C in the last century — a level that far exceeds that of global warming [2]. Figure 1 shows the distribution of the total number of hours with

Figure 1: Areas with higher temperatures in the Tokyo Metropolitan area (1981 and 1999)[3]



(The distribution of the total number of hours with temperatures above 30°C per year.)

temperatures above 30 °C; areas with higher temperatures have expanded dramatically over the last two decades.

The major causes of the heat island are: the increasing use of energy, which results in an increase of waste heat discharged into the atmosphere; the amount of evaporation (transpiration) from plants, which is decreasing due to shrinking green space – i.e., a decrease in the amount of energy converted from sensible heat to latent heat (see Footnote 1); and the thermal storage by increasing concrete buildings and asphalt pavement.

Footnote 1: Sensible heat and latent heat

Water absorbs heat from the surroundings when it evaporates. In other words, it needs heat to convert itself to water vapor. In this sense, water vapor can be regarded as a special form of energy called "latent heat." A general form of energy, meanwhile, is referred to as "sensible heat."

5.2.2 Modeling of the heat island

In order to solve the problem of the heat island, there is a need to model the phenomenon itself and evaluate the effectiveness of possible measures against it. A number of organizations and research institutes here and abroad are modeling the heat island. This section addresses a model developed by the Tokyo Metropolitan Government as a representative example.

The Tokyo Metropolitan Research Institute for Environmental Protection developed a forecasting model of mitigation measures to address the heat island. The model covers an area including Tokyo Metropolis and eight prefectures surrounding it, the radius of which is several hundred kilometers; the vertical distribution of temperatures, the direction/speed of wind, and humidity can be forecasted by this model.

The amount of artificial waste heat in the area, a factor indispensable for the calculation, is estimated based on the energy consumed by factories/businesses, residences and automobiles. Specifically, the amount of waste heat in Tokyo Metropolitan is estimated at 165 Pcal per year, about 70% of which originates in the 23 wards of Tokyo. The breakdown by source is as follows: factories/businesses, 46%; automobiles, 27%; and residences, 27%. The artificial waste-heat intensity in the 23 wards stands at some 185 Mcal/m^2 per year – more than four times the amount estimated in the cities in Tokyo, or almost one fifth of the annual amount of solar radiation in the Tokyo area, which is 990 Mcal/m^2. In particular, the intensity in the three wards located at the center of Tokyo is estimated at 358 Mcal/m^2, about one third of the total.

The forecast model is based on the following four cases:

— Case 1: Energy consumption will be reduced by some 6% through long-term, effective measures.
— Case 2: The area of parks will be doubled, while 7% of the area for buildings will be converted into green space.
— Case 3: Of the total road area, 10-20% will be paved with permeable materials.
— Case 4: Case 1, 2 and 3 (permeable

pavement: 20%) will all be put into practice.

Based on the observational data on summer days (August 31 to September 1, 1992), the climatic data that were available (temperatures, wind direction, wind speed, etc.), the effects of mitigation measures against the heat island phenomenon were forecasted for each of the four cases mentioned above. The following are the results:

a. A 6% reduction in artificial waste heat has virtually no impact on the maximum daily temperature. The minimum daily temperature, however, is reduced by 0.05 °C at the center of Tokyo.
b. Of all the mitigation measures, the promotion of urban greening is most effective in reducing the maximum daily temperature; a maximum of 0.37 °C is reduced in the northwest part of the area comprised of the 23 wards, most likely due to increased transpiration by plants. The minimum daily temperature is also reduced by 0.14 °C.
c. With 10% of the total road area paved with permeable materials, the maximum daily temperature is reduced by 0.02 °C; and with 20%, by 0.05 °C at the center of the city (less effective compared with the promotion of greening).
d. With the above three measures implemented together, the average daily temperature is reduced by 0.23 °C in the northwest part of the area comprised of the 23 wards; the maximum daily temperature, by 0.43 °C; and the minimum daily temperature, by 0.15 °C at the center of the city.

The modeling of the heat island phenomenon in the report prepared by the Ministry of the Environment shows similar results [3].

5.3 Trends in heat island mitigation technology

As already mentioned in Chapter 5.2, the promotion of urban greening contributes dramatically to mitigating the heat island phenomenon. It should be noted, however, that there is an essential difference between expanding urban green space (the trees and plants in parks, roadside trees, etc.) and promoting urban greening where flowering plants, etc., are planted in order to offer visual comfort to the citizens. In places like Japan, where land prices are very high, creating a sufficient area of green space in the city is by no means easy. And it is not feasible to dramatically reduce artificial waste heat in a short period of time.

Feasible measures for mitigating the heat island phenomenon inevitably involve the improvement of buildings, land use, and economic activities in the city.

5.3.1 Trends in the technology for shielding buildings from heat (as part of architectural engineering)

The heat island phenomenon is partly due to an increase in the temperature of external building surfaces because of solar radiation. Effective measures such as reflecting solar radiation or shielding the interior of buildings from heat are being studied.

(1) Heat reflective construction

Heat-shield coating is applied to roofs, rooftops and other parts of a building exposed to solar radiation in order to reduce the surface temperatures. Special types of coatings and coating techniques are available — e.g., a coating containing ceramic balloons (small hollow particles made of ceramic), which reflects infrared radiation, and a two-layer coating technique with the lower layer made up of a low-thermal-conductivity coating, and the upper layer of materials that reflect visible light and near infrared light of insolation.

(2) Heat insulation by rooftop greening and vegetation medium

This measure involves vegetation and its planting media on the rooftop, both of which shield the building from heat. Rooftop greening is becoming widespread in the city because of its contribution of improving visual amenity. The Tokyo Metropolitan Government, for instance, enforced the Nature Conservation Law in order to plant 20% of the total area of rooftops with vegetation.

From April 2001, moreover, an incentive system was put into place — i.e., greater floor area ratios are granted to those buildings promoting rooftop greening.

Vegetation evaporates water it absorbs from the ground, thereby cooling down the temperatures of leaves and their surroundings; it eventually prevents the temperature of the ground surface from rising by converting sensible heat of solar radiation to latent heat (see Footnote 2). By contrast, rooftop greening using plants resistant to hot and dry weather cannot lower the temperature inside the building proactively, though it shields the building from heat to some extent.

Since rooftop greening involves an increase in the live load on the building, special techniques are required for its introduction — e.g., planting of succulent plants such as Sedums (see Footnote 3). Sedums can grow on a thin planting medium that contributes to reducing both the live load and the maintenance cost. By using polypropylene and ceramic soil as materials, the thickness of a planting medium can be reduced to 50-60 mm, and its weight, to less than 40 kg/m^2, both of which are less than one third of those of a typical planting medium for turfs [5].

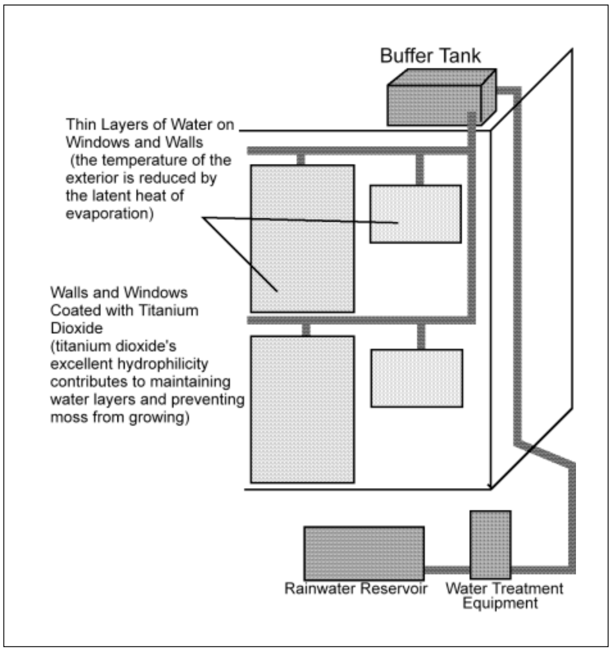
Footnote 2:

The surface temperature of vegetation that is sufficiently watered will not rise over 32 °C, according to some studies [3].

Footnote 3:

A generic name for small, fleshy CAM (Crassulacean Acid Metabolism) plants — herbaceous perennials belonging to Crassulaceae (sedum family). CAM plants open the pores to absorb CO_2 during the nighttime and convert it into malic acid. During the daytime, they close the pores to prevent the loss of water through transpiration, while reconverting malic acid into CO_2 for photosynthesis. CAM plants are very robust and resistant to environmental stresses such as hot, cold and dry weather; they can grow on infertile, thin-layer soil and require no particular maintenance.

Figure 2: Concept of exterior surface cooling system using photocatalysts [6]



(1) Cooling of surface temperatures through engineered evaporation systems

A thin layer of water on the exterior surface of rooftops and walls reduces the temperatures of the building and its surroundings — the effect of latent heat due to the evaporation of water. Materials coated with photo catalysts form a very thin layer of water on their surface. By taking advantage of this property, the amount of water necessary for keeping the surface of rooftops and walls wet can be reduced dramatically. In the case of a 10-story building, for instance, one-third to one-sixth the annual rainfall on the site of the building would be sufficient to keep its rooftop and walls wet for one month in summer (Figure 2).

Photocatalysts also add antifouling and anti-algae properties to wall materials, thereby reducing the maintenance cost of the building. A prefabricate cottage was previously set up using materials coated with titanium dioxide, a typical photocatalyst; a thin layer of water was formed on its exterior surface. The results: the temperature of its interior was about 10 °C lower than that of the interior of an ordinary cottage [6].

(2) Proactive use of fresh air for high-rises

Because of the widespread use of IT equipment in an office, some high-rise office buildings need to be air-conditioned even during the winter months. In a bid to reduce the amount of energy consumed by mechanical air-conditioning, therefore, the construction of a new-type of high-rise is under study; its concept is to introduce cool, fresh air directly into the office. Unlike low-rises, the windows of which can be opened and closed, introducing fresh air into the interior of high-rises requires new techniques. Several methods have been developed in order to address this problem — e.g., a control system responding to exterior climatic conditions (temperatures, humidity, etc.), a design of air ducts in consideration of equipment layout plans of the office, and a simulator for controlling the heat environment [7].

5.3.2 Trends in the studies of cooling technology (as part of urban environment engineering)

(1) Studies of new paving materials

Since most of the road in the city is paved with non-permeable materials such as asphalt, water does not evaporate through the pavement — a clear contrast to land covered with vegetation. Thus, cooling by the consumption of latent heat rarely takes place in the city. In addition to this, several problems associated with non-permeable pavement have been pointed out from the viewpoint of hydrology — e.g., rainwater in the city immediately flows into sewage-treatment plants. In order to address these problems, there have been some attempts to commercialize permeable pavement. Their basic idea, however, was to make the pavement permeable by means of fine pores, most of which clog over time; although permeable, non-water-retentive paving materials did not create much of an evaporative cooling effect.

Other R&D are underway, the common idea of which is to impregnate paving materials with chemical absorbents or dehumidifying agents (chlorides), thereby providing the materials with water retentivity and the properties of absorbing and releasing moisture. Cost reduction efforts are also underway by using seawater as a material for producing chlorides [8].

There are some examples where the performance of paving materials having both permeability and water retentivity was tested in the field [9]. Specifically, powdered blast furnace slag (a byproduct of the iron-making process) was used as a water-retentive material, which was then filled in part of the openings of the drainage asphalt pavement to provide it with both of the properties.

(2) Studies for using groundwater as a heat sink

Conventional air-conditioners release heat into the atmosphere through their heat exchangers. New technologies are being developed for transferring exhaust heat to groundwater through heat pipes buried underground. This method is expected to contribute to mitigating the heat island phenomenon, since it does not involve any release of heat into the atmosphere [10].

(3) Studies for selecting plants with high transpiration capacity

Plants absorb water through their roots and the absorbed water evaporates from the leaves. This transpiration capacity of plants (evapo-transpiration) can be compared to a powerful, low-cost "pump" that removes water from the soil. There are some plans for taking advantage of this particular capacity — e.g., using plants to absorb both water and toxic substances from polluted soil, or in the case of arid countries, planting vegetation all over the soil of waste dumping areas to pump rainwater into the atmosphere, while preventing it from permeating through the waste layers [11].

This "pumping effect" of plants can be used to cool down the atmosphere. In other words, it is possible to mitigate the heat island phenomenon by activating the transpiration capacity of vegetation, which in turn requires the selection and introduction of optimal vegetation. Informative studies are underway in the U.S. and other countries for selecting plants with high transpiration capacity, the purpose of which is to materialize the phytoremediation of polluted soil [12].

5.4 Evaluation of the impact of energy supply systems

A variety of mitigation technologies mentioned in the previous chapter are expected to mitigate the heat island phenomenon without interfering with the current economic activities. Meanwhile, decentralized power sources such as fuel cells and gas turbines — cogeneration systems with higher energy efficiency — will probably become widespread in the city. Accordingly, small-scale energy supply systems designed for specific buildings or districts are expected to emerge in the near future.

5.4.1 *Ideal energy supply systems and their waste heat*

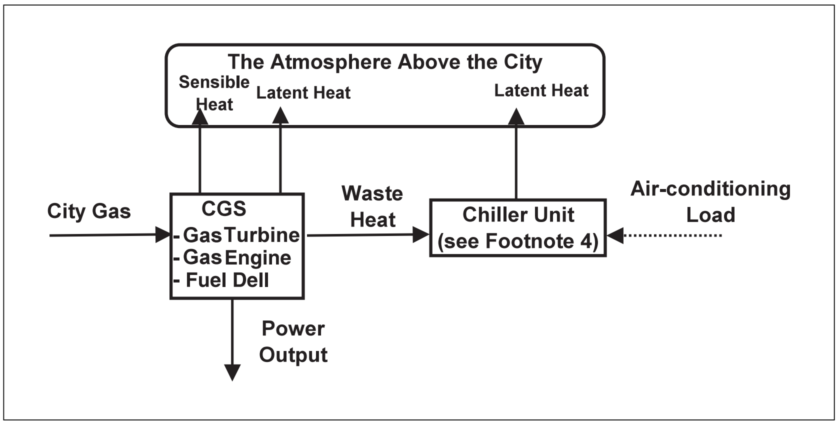
Electric equipment including the air-conditioners of buildings in large cities depends largely on the electricity supplied through electric grids. Power plants, however, are generally located outside urban areas, and their power generation efficiency stands at 40%, more or less. Put differently, about 40% of the potential thermal or nuclear energy is converted into electricity, while the rest is discharged into the sea as waste heat energy.

The power consumption and heat load on the part of energy users, namely offices and residences, fluctuate by day and month, and their patterns do not synchronize with each other [13]. For this reason, distributed power sources are forced to operate in accordance with load fluctuations. In the case of fuels cells and gas turbines (both of which are considered promising distributed power sources), however, lowering of load results in lower power generation efficiency [14-16]. Taking fuel cells as an example, the power generation efficiency at 100% load factor stands at some 40%, while it decreases to some 36% at 25% load factor (some data show that in the case of 1 kW class solid-oxides fuel-cells, the power generation efficiency of direct current output at 1 kW is about 25%, while it decreases to some 15% at 500 W output. [17]) As for gas turbines, the power generation efficiency at 100% load factor is about 32%, which decreases to about 20% at 25% load factor. The heat energy being discharged into the sea will be brought into the city together with distributed power sources. Moreover, their lower power generation efficiency means that a massive amount of waste heat will be generated — a situation that will further accelerate the heat island phenomenon.

5.4.2 *Evaluation of the amount of waste heat generated by energy supply systems*

A group of Dr. Yutaka Genchi of National Institute of Advanced Industrial Science and Technology (AIST) [18] and another group led by Assistant Professor Yoshiyuki Shimoda at Osaka University [19] are currently conducting studies on the ideal energy supply system and its relation to the heat

Figure 3: Concept of energy flow incorporating a cogeneration system [18]



Footnote 4:

A chiller unit is a cooling device that uses water or air as a refrigerant. The refrigerant in the primary circulation absorbs the heat generated by mechanical equipment; the heat absorbed is then transferred to the refrigerant in the second circulation, which is eventually dissipated either through evaporation or air cooling.

island phenomenon.

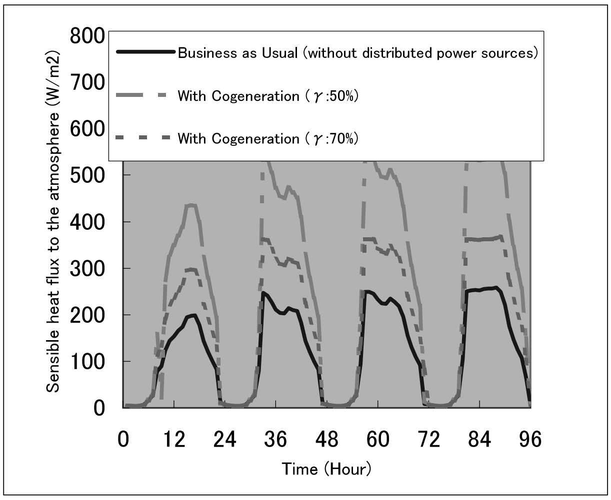
Based on an energy flow that incorporates a cogeneration system (CGS) (see Figure 3), Genchi's group simulated the amount of heat discharged into the atmosphere above the Dojima district of Osaka City as well as changes in temperatures. This simulation used the weather observation data for the period between July 29 and August 2, 2001.

Figure 4 shows hourly fluctuations in the sensible heat flux to the atmosphere. It compares the case without distributed power sources to that based on CGS with varying combined efficiency (γ: power generation efficiency + heat efficiency). At 70% combined efficiency, the amount of sensible heat discharged is almost consistent regardless of the introduction of distributed power sources, whereas at 50% combined efficiency their introduction results in more than twice the amount of sensible heat discharged under the case without distributed power sources; an increase in the temperature is estimated at 0.7 °C.

Shimoda's group, meanwhile, is conducting research on how the energy use in each sector of consumer, industry and transportation would influence the temperature in Osaka. Specifically, the group quantified the amount of each energy source (electricity, oil, city gas, etc.) consumed by each sector, and evaluated how the waste heat would be distributed to sensitive heat, latent heat and water systems. In all of Osaka, the total of sensitive heat and latent heat — the annual average of the amount of energy discharged — corresponds to some 10% of the amount of the total solar radiation in the area. Incidentally, the amount of energy discharged is almost equal to the amount of solar radiation in dense city area like Midosuji.

Shimoda's group also conducted a case study of the energy flow in all of Osaka based on the large-scale introduction of regional cogeneration systems. Dividing Osaka into 0.5 km-square areas, the group studied changes in energy flows in the case of introducing CGS (gas turbines using city gas as fuel) into areas, the heat demand density of which is 1 Tcal/ha per year. The power generation efficiency of the gas turbines was assumed to be 30%. Designed to cogenerate heat and power, CGS

Figure 4: Hourly fluctuations in the amount of sensible heat discharged into the urban atmosphere



can operate in response to daily fluctuations in electricity and heat demand. Based on this characteristic, three types of operations were set for CGS: generating all the electricity needed in the area, while supplying part of its heat demand (power-oriented operations); generating all the heat needed in the area, while supplying part of its electricity demand (heat-oriented operations); and generating the electricity without heat excess or supplying heat without electricity excess in the area (no excess capacity). In line with these types of operations, the group evaluated the effect of introducing CGS, compared with the energy supply dependent on thermal plants. According to the results of this case study, the energy-source mix before introducing CGS – heavy oil, kerosene, city gas and grid electricity – will be narrowed down to city gas and grid electricity in all of the operations after the introduction of CGS. Consequently, the total energy consumption is expected to decrease by 10-15%. Regardless of the type of an operation, however, the amount of waste heat in the area will increase since only part of waste heat can be utilized in the region.

5.5 Conclusion

The average temperature in July 2002 at the center of Tokyo was 2.5 °C higher than that in a normal year, and temperatures topped 30 °C in 24 days – the record-breaking hot summer of 1994 is becoming a norm. This trend is creating a vicious circle in terms of energy use. Specifically, the worsening heat island phenomenon in the city boosts demand for air-conditioning during the summer, and along with it, the consumption of energy such as electricity, which in turn generates waste heat that would further accelerate the heat island phenomenon.

Mitigation technologies targeting buildings, etc., should thus be developed and promoted, as mentioned in Chapter 5.3. These technologies, however, are all based on the premise that the current production activities and life styles are maintained. In other words, their aim is to pursue measures for maintaining the living standards of a city plagued with the heat island phenomenon. In discussing long-term measures in the future, therefore, there is a need to study the impact of energy use on the mechanism of the heat island.

In the meantime, distributed power sources centered on fuel cells are expected to become widespread in the city and industrial facilities in its suburb in around 2010. As already mentioned, the introduction of the existing distributed power sources, the combined efficiency of which is 40-60% (depending on load conditions), will accelerate the heat island phenomenon. What is needed from the viewpoint of mitigating the heat island phenomenon, therefore, is to develop power sources that can be operated at higher power generation efficiency and heat utilization efficiency within the range of fluctuations in users' demand for heat and power. There is also a need to develop advanced simulation analysis technology to evaluate how the improved distributed power sources and the mitigation measures mentioned in Chapter 5.3 will mitigate the heat island effect. In addition, the development of technology for transferring waste heat generated by distributed power sources to the sea, rivers and ground (media that can absorb a massive amount of heat) holds the key to the success of the efforts.

Discussions about the heat island and measures against it will inevitably wind up in the environment-versus-economy argument. One widely held view is that the only solution to this problem is to review the very concept of the city. For instance, a concept called "compact city" has been proposed — i.e., there should be an optimum scale for each city in view of its living environment including commuting, and, hence, it should be possible to maximize the economic value of the city while minimizing the associated environmental issues at the same time. Although it is by no means feasible to dramatically convert large cities, namely the center of the social system, into compact cities in line with this concept, it may be possible to divide such large cities into compact cities in phases by creating green spaces and promoting energy-efficient buildings when developing urban renewal projects. The creation of a realistic image of a future city, in which a comfortable living environment and efficient energy use go together, holds the key to developing effective measures against the heat island effect.

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6

Trends in Research and Development of Fine-Grained Metallic Materials

— Aiming at the Next-Generation High Strength Materials —

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6.1 Introduction

Metals are basic materials for industry; especially, steels are the most commonly used metallic materials utilized as structural materials. As industrial technologies are developed, requirements for mechanical and functional properties of metals become higher and higher, demanding superior materials with such properties as lightweight, high strength, and long service life. On the other hand, domestic demand for steel has decreased to about 60 million tons in 2000 from about 80 million tons in 1990 as a result of the maturity of society, and the recovery of the demand for steel cannot be expected in the future. While the demand for steel is decreasing, generation of scraps is gradually increasing, and it is expected that the generation of scraps will become equal to the production of steel in around 2030.[1] Therefore, in order to answer the social requirements for energy saving, resource conservation and environmental protection, it is of urgent necessity to develop materials having high recyclability in addition to lightweight and long service life.

In the past, technologies such as heat treatment and addition of alloying elements have been used to improve the properties of metals; however, it has become impossible to satisfy the above-mentioned new requirements for advanced properties relying only on these technologies. In order to effectively utilize resources and energy, breakthrough technologies that provide high recyclability and excellent environmental friendliness, as well as making the most of the characteristics of materials, are strongly sought for.

It has been confirmed by recent basic studies that properties of metals such as strength, toughness*1, and corrosion resistance are significantly improved by refining the grain size.[2, 3] Establishing the technology to create structural materials for general use with high strength and highly functional characteristics will greatly contribute to the economy and social life by enhancing the foundations of society for secure safe social life and by constructing a sustainable society. According to one estimate, for example, the use of materials having "double strength and double service life" will reduce the total emission of CO_2 in Japan by 2 to 3% due to the improvement of fuel consumption rate resulting from the reduction in vehicle weight.[1]

This report, while laying stress on ferrous materials, summarizes the past achievements and future trends in the research and development of fine-grained metallic materials targeting the creation of light and strong materials.

6.2 Strengthening mechanisms of materials

Various methods are known as means to strengthen materials, all of which make it a basic principle to restrict the motion of dislocations (disorder of atomic arrangements) in crystals so as to suppress plastic deformation (hardening), which is the permanent deformation beyond the elastic deformation range. The strengthening mechanisms are classified according to the processes to restrain the motion of dislocations as follows:[5,6]

(1) Solid-solution strengthening

A strengthening mechanism in which impurity atoms are introduced into crystals to form a solid solution*2 in order to restrain the motion of dislocations.

(2) Dispersion strengthening and precipitation strengthening

A strengthening mechanism in which the motion of dislocations are suppressed by fine particles (second-phase particles) that are dispersed in crystals. In precipitation strengthening, the second phase is precipitated from a solid solution, whereas the second phase is formed by other processes than precipitation (e.g., formation of oxide particles) in dispersion strengthening. Precipitation strengthening is particularly important from the practical point of view, and most of the strengthening processes for ultra-high tensile strength steels, aluminum alloys, and titanium alloys employ this mechanism.

(3) Phase transformation strengthening and strengthening by martensitic transformation

A strengthening mechanism in which fine, dense structures are formed by rapid cooling from high temperature ranges. The martensitic phase in the Fe-C system is a typical example.

(4) Strengthening by grain refinement and strengthening on the grain boundaries

A strengthening mechanism in which the grain size is made very fine. The difference of the strength of material increases in inverse proportion to the particle size raised to the power of 0.5, and it is known by experience that the relationship between yield strength (or tensile strength) σ_y and particle diameter d is expressed by the following equation,

$$\sigma_y = \sigma_i + k_y d^{-1/2} \text{ (Hall-Petch's relationship)}$$

where σ_i is the average yield strength of single crystals and k_y is a parameter that represents the effect of grain boundaries on the increase of yield strength.

(5) Work hardening and strain hardening

A strengthening mechanism in which materials are hardened by increasing the number of dislocations as a result of plastic deformation of crystals. When the hardened material is heated, the strength obtained by the work hardening is lost through three stages: recovery, recrystalization, and grain growth.

The mechanisms (4) and (5) are based on inherent characteristics of material in the sense that the additional strength is obtained without changing the composition of the material to be strengthened. In consideration of such conditions as weldability and possibility of recycling, the choice of the appropriate method for a particular application is limited. In the strengthening by grain refinement, in addition to the increase in strength due to the grain boundary effect, materials become tougher because the ductile-brittle transition temperature*3 is lowered. On the other hand, in the work hardening, materials become brittle because the ductile-brittle transition temperature*3 is raised making the process less practical.[7] Furthermore, the development of basic research has revealed that "ultra-refinement in a simple-component system" may provide not only additional strength but also ductility, toughness, durability and corrosion resistance[2,3], making the grain refinement process the most promising method for material strengthening.

6.3 Outline of the various projects for developing fine-grained metallic materials

6.3.1 *Ferrous materials*

The development of fine-grained metals is most intensively advancing in ferrous materials. Since ferrous materials are the most widely used among the structural materials, breakthrough technologies for weight saving and strengthening of steel have far more impact on society than any other material. Table 1 shows the outline of representative projects for developing fine-grained steels in Japan.

Table 1: National projects for fine-grained steels

Project name	Period	Major executing organization	Target of development
New millennium structural materials "Ultra-Steel" (STX-21)	First stage: 1997 to 2001 fiscal year	Frontier Research Center for Structural Materials, National Research Institute for Metals of Science and Technology Agency	**First stage**: Development of "double strength and/or double life" steels
	Second stage: 2002 to 2006 fiscal year (scheduled)	Steel Research Center, Independent Administrative Institution National Institute for Materials Science (NIMS)	**Second stage**: Creation of "Factor 4" steel used for "new urban infrastructures" and "high-efficiency coal-fired power plants" (doubling the strength and life at the same time).
Super Metal Technology (Ferrous material)	1997 to 2001 fiscal year (1995 to 1996 fiscal year, leading research for super metal)	The Japan Research and Development Center for Metals (Nippon Steel Corp., NKK Corp., Kawasaki Steel Corp., Sumitomo Metal Industries, Ltd., and Kobe Steel, Ltd.)	To establish the technology to create fine-grained steel that is at least 1 mm thick in shape and has a grain size of 1μm or less by obtaining uniform multi-phase structures.
Developmsent of basic technology for creating ultra-fine grained steels harmonious with the environment (Super Metal 2)	2002 to 2006 fiscal year (scheduled)	Undecided as of July 9, 2002	To develop basic technologies for forming, processing and utilizing ultra-fine grained steel with an intention for application to the steels widely used in the automobile industry.
Nano Metal Technology	2001 to 2005 fiscal year (scheduled)	The Japan Research and Development Center for Metals (Nippon Steel Corp., NKK Corp., Kawasaki Steel Corp., Sumitomo Metal Industries, Ltd., and Kobe Steel, Ltd.), Osaka Science and Technology Center, Hitachi Metals, Ltd.	1. **Ultrahigh-purity metals** To develop and systematize the structure control technology, laying stress on the composition control technology that enables the reduction of impurity elements in metals to the order of nanograms. 2. **Practical metals** To elucidate the nano-cluster and nano-precipitation behaviors and the behaviors of micro grain boundaries and interfaces in the nano-range of steels, in order to establish the guiding principles for structure control and the basis of designing and processing technologies that will lead to the creation of new generation multi-phase steel by nano-control.

Sources: Authors' compilation on the basis of references [1, 2, 3, 11, 13, 14] and [15]

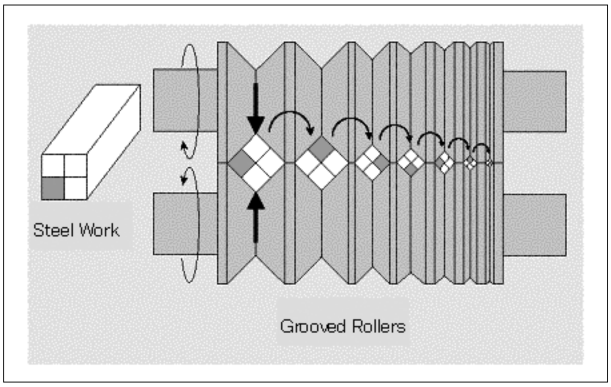
Present status of each project is as follows.

• Ultra-Steel (STX-21)

In April 1997, "Research on structural materials for the new millennium (Ultra-Steel) project" (STX-21) started at the Frontier Research Center for Structural Materials, the National Research Institute for Metals of Science and Technology Agency, which is now reorganized as the Steel Research Center of the Independent Administrative Institution National Institute for Materials Science (NIMS). The target of this project is to develop steels having "double strength and/or double life." More specifically, the target is to realize easily recyclable steels having properties of "double strength and/or double life" that do not require the use of rare metal alloying elements, taking the conservation of resources and protection of the environment into consideration. In the first stage of the project (1997 to 2001 fiscal year), the following four subjects were chosen. Subjects relating to the enhancement of the strength of steels are: (i) development of easily recyclable and weldable ultra-fine grained steel of 800 MPa (megapascal) class (800 MPa is twice the tensile strength of the present typical 400 MPa structural steels), and (ii) development of ultrahigh-strength steel of 1500 MPa class that is resistant to delayed fracture and fatigue; and subjects relating to the elongation of life were: (iii) development of alloying-element saving, high performance steel that is resistant to marine environments, and (iv) development of heat-resisting steel used for the ultra-supercritical pressure power station. These studies proved on the laboratory level that it is possible to create ultra-steel.[8]

Figure 1 is a schematic diagram of the rolling process employed in the development of 800 MPa steels in this project using multidirectional caliber rollers.[7] This method is a rolling process using multidirectional grooved rollers, and a kind of multi-pass, multidirectional warm working. By repeating the rolling of a steel rod in two directions (vertically and horizontally) in the temperature range of warm working under heavy deformation, a rod of 18 mm square and 20 m long having ultrafine grains of 1 μm was successfully obtained. As the material to be tested, low-carbon silicon manganese steel was chosen, which is widely used and easily recycled.

Figure 1: Schematic diagram for rolling using multi-directional grooved rollers



Source: reference [7]

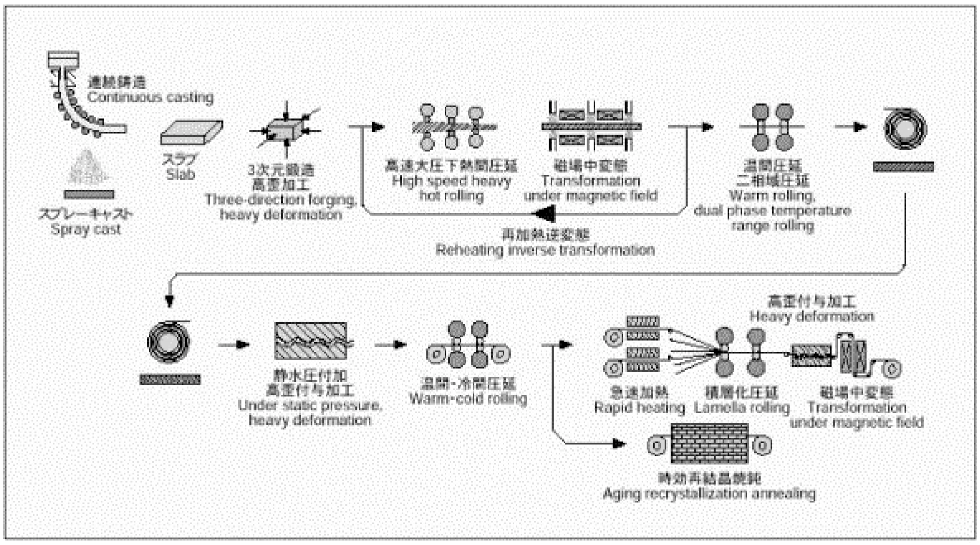
In the second stage of the STX-21 project scheduled for 2002 to 2006 fiscal year, "Ultra-Steel project aiming at realizing new social and urban infrastructures," the target is to establish the technology to create "Factor 4" ultra-steel that doubles the strength and life. "New urban structures (such as tall buildings and ultra-long bridges)" and "high-efficiency thermal power plants (5% higher power generation efficiency of coal-fired power plants by raising the steam temperature from 600°C to 650°C)" have been selected as the targeted structures, and basic studies are scheduled to be started from the laboratory level taking the commercialization viewpoint into consideration so that development research can be started after five years.[9] In order to promote this project, the Steel Research Center was organized in NIMS this April.[10]

• Super Metal

The "Super Metal Technology" project was started in New Energy and Industrial Technology Development Organization (NEDO), based on the Program for the Scientific Technology Development for Industry sponsored by Ministry of International Trade and Industry (present Ministry of Economy, Trade and Industry). After conducting leading research for two years from the 1995 fiscal year, the project was carried out for five years from the 1997 fiscal year. There are two major subjects for the super metal project: technology for creating mesoscopic*4 structured steel (ferrous super metal), and technology for creating mesoscopic structured bulky aluminum materials (aluminum super metal). The ultimate target for the ferrous super metal is "to establish the technology for manufacturing microstructure steel with grain size of less than 1 μm and a thickness over 1 mm using carbon steel and by even multi-phase structuring." This has been planned based on the basic metallurgical concept for producing fine-grained steel constructed from the results of the leading research. The results made it clear that heavy deformation caused by working is effective for creating ultrafine grained steel, and that making a structure of simple composition steel ultrafine without adding special alloying elements is the best way to make the most of the ultimate properties of steel and improve recyclability. [2,3]

Therefore, they have carried out research selecting the following three major themes: (i) research on ultra-refinement of steel structure by giving heavy deformation by hot working; (ii) research on ultra-refinement of steel structure by working and heat treatment under a strong magnetic field; and (iii) estimation studies on the structure and characteristics of ultrafine grained steel with multi-phase structure. The driving force for nucleation in transformation and recrystalization processes was dramatically increased by the heavy deformation caused by hot working, and the growth of nuclei was thoroughly suppressed by making use of the second phase. In this way, they have practically established the guiding principles for obtaining ultrafine grain size of 1 μm or less in the process of ultra-refinement of steel. Then, using a high-speed, heavy-reduction rolling mill, they produced a fine-grained steel plate by hot rolling of laboratory scale, and succeeded in obtaining a 5-mm thick steel plate having a grain size of less than 1 μm. The fine-

Figure 2: Schematic diagram for the manufacturing process of ferrous super metals



Source: "Super Metal" Web site of NEDO [13]

grained steel plate having a strength of 900 MPa class obtained without adding alloying elements proved the improvement in strength and toughness, and it was confirmed that they had achieved the objective of the project.[11, 12] Figure 2 shows a schematic diagram for the manufacturing process of ferrous super metal.

Reflecting the recognition that it is necessary to elucidate the mechanism of grain refinement, basic studies to elucidate the mechanism of grain refinement are being conducted in the Nano Metal project that started in the last fiscal year.

Taking the results of the super metal project into account, a succeeding project, "Development of basic technology for creating ultra-fine grained steel harmonious with the environment (super metal 2)" is scheduled to newly start from the 2002 fiscal year as a part of the 3R (Reduce, Reuse, and Recycle) project sponsored by NEDO. The development period of this project is scheduled to continue for five years, and its target is to develop basic technologies relating to ultrafine grained steel including forming processing and utilization technologies that can be applied to widely-used steels such as those for automobile manufacturing. There are four research and development themes for this project: (i) advanced heavy deformation working technology; (ii) innovative rolling and lubrication technology; (iii) innovative joining technology; and (iv) research and development of a heavy deformation working model making use of computational science.[14]

• **Nano Metal**

In the 2001 fiscal year, the "Nano Metal Technology project," which is scheduled to continue for five years, was started as a part of the "Materials Nanotechnology" program of NEDO.[15] "Materials Nanotechnology," the innovative technology of the 21st century, is expected to radically change the technologies related to materials, which is the basis for various fields of industry including information, environment, safety, security and energy. The "Materials Nanotechnology" program aims to carry out basic research and development on material nanotechnologies, and to systematize the knowledge obtained from the results.

An objective of this project is to dramatically improve mechanical properties (e.g., strength and ductility) and functional characteristics (e.g., corrosion resistance, electrical properties, and magnetic properties) by ultra-precise and ultra-fine control of the composition and structure of metallic materials. Such technologies will provide light and heat-resistant materials for various fields of industry including the automotive industry and information industry, contributing to the promotion of energy saving. It is a further objective of the project to establish "nano-metallurgy" (metallurgy at the nano-level) by systematizing the obtained knowledge and to build the technological basis for creating new metallic materials. To realize these objectives, it is planned, relating to metallic materials, to establish ultra-precise crystal composition control technology (e.g., purification and addition of effective elements), ultra-precise and ultra-fine crystal structure control technology (e.g., grain size control, precipitation control, and structure control of grain boundary/interface), and measuring techniques for composition analysis and structure analysis as well as to systematize these technologies. Specifically, the following four themes have been selected: (i) composition control technology for metals in the nano range; (ii) structure control technology for metals in the nano range; (iii) design technology for metallic materials making use of calculation science; and (iv) the systematization of technologies. In pursuing these themes, it is intended to emerge from the metallic material creation technology hitherto that resorts to empirical and experimental methods; to enable development of metallic materials having highly-advanced functions and to provide metallic materials with desired functional characteristics; to deal with resource conservation, energy saving, and global environmental issues; to establish a secure and safe society; and to contribute to the realization of nano-devices that open the road to next-generation information communication.

6.3.2 Nonferrous metals

Although we have so far introduced technology development projects mainly related to fine-grained ferrous materials, in the nonferrous metal field developments of fine-grained materials are also being carried out relating to aluminum and copper materials. Table 2 shows the outline of major national projects relating to fine-grained nonferrous metals. Among the specific themes are: development of thin aluminum sheets for automobile application from the viewpoint of reducing vehicle weight, development of high-performance wrought copper products having high conductivity and strength two times that of conventional materials or more, and realization of ultra-fine thin film copper wiring of less than 100 nm wide for next-generation Si devices.[16]

6.4 Developing practical fine-grained steel

On November 1, 2001, Nakayama Steel Works, Ltd. announced that they had succeeded in producing hot rolled fine grain steel plates for the first time in the world and started production and

Table 2: National projects for fine-grained nonferrous metals

Project name	Period	Major executing organization	Target of development
Super Metal Technology (Aluminum Materials)	1997 to 2001 fiscal year (1995 to 1996 fiscal year, leading research for super metal)	The Japan Research and Development Center for Metals	To establish the technology for creating bulky aluminum materials having an ultra-fine grain size of about 3μm or less, mechanical properties (strength and corrosion resistance) 1.5 times better than those of conventional materials of the same kind, and a sheet width of about 200 mm or more.
Nano Metal Technology (Aluminum Materials)	2001 to 2005 fiscal year (Scheduled)	The Japan Research and Development Center for Metals (Furukawa Electric Co., Ltd., Sky Aluminum Co., Ltd., and Sumitomo Light Metal Industries, Ltd.)	Relating to aluminum alloys of practical compositions, to elucidate the structure in the nano range and its formation mechanism, to establish the structure control technology, and to systematize the technology by constructing a database of material properties.
Nano Metal Technology (Copper Materials)	2001 to 2005 fiscal year (Scheduled)	The Japan Research and Development Center for Metals (Yamaha Metanix Corporation, and Nippon Mining & Metals Co., Ltd.)	(1) **Bulk group** To establish basic technology for producing high-strength, high-conductivity copper materials by controlling nano-clusters and grain size. (2) **Thin film group** To establish the guideline for designing the materials, and processing of high-conductivity materials for the wiring of next-generation highly-integrated devices.

Sources: Authors' compilation on the basis of references [13] and [16] sales of them on commercial basis.[4] In this original technology for producing hot rolled fine grain steel plates, which has been developed in cooperation with Kawasaki Heavy Industries, Ltd., high-reduction rolling and vigorous cooling are repeated to produce the product. Using six continuous finishing rolling mills, the thickness is drastically reduced to less than half with the last three mills, and, at the same time, the material is rigorously cooled (cooling speed: 40°C/sec) by curtain wall cooling systems installed between the rolling mills. Table 3 shows the progress of development of hot rolled fine grain steel plates at Nakayama Steel Works, and Figure 3 shows a schematic diagram of the production process.

These steel plates have a very fine grain size of 2 to 5 μm, which is less than one-third that of conventional materials (grain size of conventional steels is between 10 and 15 μm), and a tensile strength of 500 to 600 MPa class, which is from 1.5 to 1.6 times that of conventional steels. As the strength was increased by grain refinement, it is possible to reduce the Si and Mn content of conventional hot rolled steel plates to half. Furthermore, the new material shows high toughness, high workability and excellent weldability, as well as high resistance to fatigue. Although the strength attained does not reach 800 to 900 MPa, the target value of STX-21 and Super Metal (ferrous materials) projects, it is highly appreciated that they have realized a practical fine grain steel having a grain size of several micrometers and have put it into practical use and mass production in advance of the national projects.

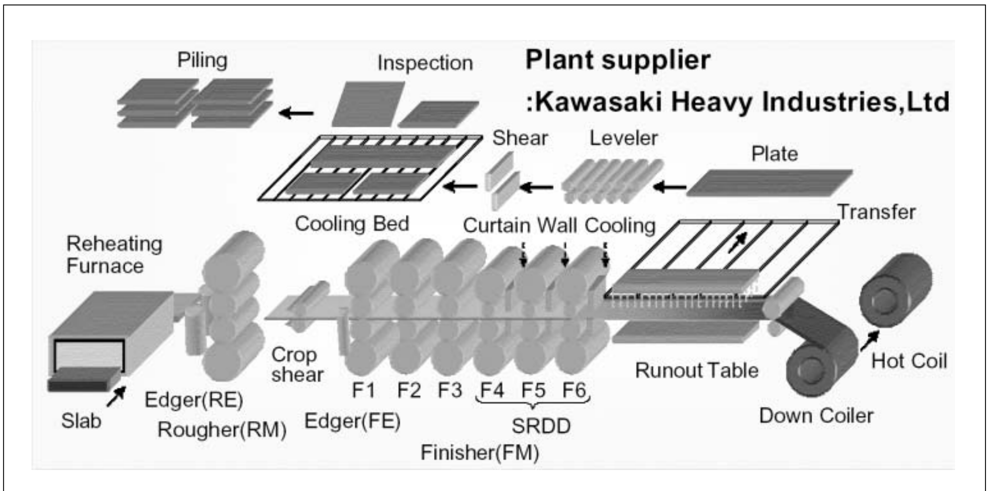
The production technology of this material cleverly combines the high reduction rolling technology using the single roll drive with different diameter rolls*5 and the vigorous cooling technology using curtain wall cooling systems*6, and has attracted the attention of the industry. The fact that manufacturers of industrial machinery, construction equipment, and automobiles are requesting quotations for sample

Table 3: Progress of the development of hot rolled fine grain steel plates at Nakayama Steel Works, Ltd.

Product name	Progress of development	Executing organization	Outline of the development
Hot rolled fine grain steel plates NFG (Nakayama Fine Grain)	**1996:** Planning the construction of the hot rolling plant. **January 2000:** Started hot line test. **August 2000:** Started commercial operation. **January 2001:** Started full-scale development of hot rolled fine grain steel plates. **October 2001:** Succeeded in developing a steel with a tensile strength of 500 to 600 MPa class. **November 1, 2001:** Press release. **December 2001:** Started production and sales.	Nakayama Steel Works, Ltd., Kawasaki Heavy Industries, Ltd.	Developed hot rolled fine grain steel plates having a grain size of 2 to 5μm, which is less than one-third that of conventional materials and a tensile strength of 500 to 600 MPa class.

Source: Authors' compilation on the basis of reference [4]

Figure 3: Schematic diagram for the production process of hot rolled fine grain steel plates at Nakayama Steel Works, Ltd.



Source: reference [17]

delivery indicates that much hope is placed on the material. At present, the range of dimensions that can be produced is limited to 1.6 – 16 mm thick × 600 – 1219 mm wide, but it is expected that the strength will be increased as well as the dimensions that can be produced in order to expand the fields of application.

6.5 Present status in foreign countries

Innovative projects such as "STX-21" and "Super Metal Technology" have made an impact on research activities on fine-grained steel in foreign countries, and Europe, Korea, and China have independently started projects of fine-grained steels aiming to catch up with Japan.

6.5.1 Europe: ECSC Steel Program [18]

The first-stage project for ultrafine-grained steels started in 2000, as a one-year EU project. Research mainly on "heavy deformation rolling + annealing" was carried out in order to investigate the properties of steels with a grain size of 1 μm and evaluate their effectiveness.

Furthermore, a three-year ECSC (European Coal and Steel Community) project, whose participants are mainly private companies and universities, started in 2001 for developing controlling technology of fine structure to provide high strength. It is intended to apply the results of the project to industrial fields such as automobile manufacturing, buildings and infrastructures, and pipelines. The target is narrowed down to the development of an extra-high speed cooling technique and production of fine-grained steel using hot rolling lines in order to create steels with a grain size of 2 to 3 μm, which seems to be rather easy to realize, and to attain prospects for the technology. Practical application of steel plates and rods to the automobile industry without making significant changes in the manufacturing process is being considered. Efficient and consistent research and development is being made from the preparation of hot-rolled material, through processing, to characterization. Weldability is considered to be a key issue; however, experiments on punch joining and other methods that can substitute spot welding are being made.

The new ECSC2002 Project scheduled from 2002 to 2007 has started, and it is aimed at searching for high performance, durability, and recyclability.

6.5.2 Korea: HIPERS-21 [18]

The five-year Hipers-21 project started in 1998, and studies on ultra-refinement of grain size is being conducted, making use of dynamic transformation induced by strain as in the case of the Japanese Super Metal Technology project. They have reported that strain induced dynamic transformation (SIDT) is effective for creating fine-grained steels, and that dispersion of TiN particles is effective for suppressing the grain growth in the heat affected zone (HAZ). The average grain size of created fine-grained steel is fine in the surface layer at 2 to 3 μm, but coarse in the center part at 5 μm. Not only the steel industry but also the heavy industry and construction industry are participating in the project, and specification design from the practical point of view is also being investigated.

In the second-stage project scheduled from 2003 to 2007, the following themes are planned based on the results of the first-stage project: (i) research and development of a production method for new ultrafine-grained steel; (ii) development of a pilot plant for the new ultrafine-grained steel; (iii) proving the production method for ultrafine-grained steel; and (iv) research on the application of the ultrafine grain steel to large-scale structures.

6.5.3 China: New Generation Steels [18]

The national project, "New Generation Steel," started in 1998 aiming at "double strength and/or double service life" with grain refinement, purification and homogenization as the key technologies. Realization of fine-grained structural steel with a grain size of 2 to 3 μm is targeted, and the actual objective is to catch up with Japan. They are positively collecting information from Japan, by frequently holding international conferences.

In the United States, on the other hand, no research project for fine-grained steel exists at present. However, in the "National Nanotechnology Initiative" announced by then

President Clinton, it was mentioned as an example of the Grand Challenges to develop materials that are ten times stronger but lighter than steel. And we should keep an eye on the future movements in research and development.

6.6 Conclusion

In addition to higher strength, grain size refinement of metallic materials has brought about various improvements such as a lower ductile-brittle transition temperature, better corrosion resistance, ductility and weldability. As a result, metallic materials that have been considered as structural materials are now recognized as new functional materials owing to the new functions created by innovative processing. In order to promote further improvement of material properties and establish control techniques, it is necessary to develop, in addition to the grain size control, advanced technologies for designing and controlling composition and precipitation within the fine structure as well as to elucidate leading principles for these studies. A technological breakthrough is also required for putting these materials into practical use. For example, it is hoped that, while the properties of a fine-grained material are maintained, the technology that enables joining will be developed.

Since the development of such materials requires not only large-scale equipment such as full-sized rolling mills but also a long period of research and development activities that separate private companies cannot afford, the roles of national projects become very important. In the projects for the development of fine-grained metallic materials, mutual exchange of information has been actively done. Particularly in Workshop on the Ultra-Steel, international committee on ultrafine grains, International Conference on Advanced Structural Steels and the Intensive Forum held by the Iron and Steel Institute of Japan, researchers actively discussed technical matters for the sake of mutual communication, significantly contributing to the advancement of Japanese technological development relating to steel and other metallic materials. Five years have passed since the research and development of fine-grained metallic materials started, and it seems to be about time to evaluate the results. From now on, it is necessary, in addition to the development of material and processing conducted by the material industry that has the seeds, to develop applications from the viewpoint of practical use in industries that have the needs. Materials can be called materials only when they are practically used. Therefore, effective and sufficient research and development must be conducted by unifying the direction of development, with close communication among the material industry, researchers of materials and processes, end users of materials, and product designers. Especially, adequate cooperation among the national projects, STX-21 second phase, Super Metal 2, and Nano Metal is essential for the attainment of technology breakthrough.

The recent growth of the iron and steel industry in China and Korea is magnificent. They are now competing with Japan backed by the newest equipment and low labor costs. For the Japanese iron and steel industry, as well as the other metal industries, to keep the position of basic industries maintaining international competitiveness, it is necessary to distinguish their products by adding extra values. Japan is now running ahead of other countries in the development of fine-grained metallic materials with fine-grained steel as a major target. In order for the Japanese material industry to maintain sufficient international competitiveness and attain the position to establish de facto standards in material development, significant roles are expected from these projects.

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Glossary

*1 Toughness

Property that indicates how much energy can be absorbed before fracture. The higher the toughness, the tougher is the material.

*2 Solid solution

State in which foreign atoms are present as solutes in the crystal lattice of a metal in solid state.

*3 Ductile-brittle transition temperature

The temperature at which the fracture mechanism of steel changes from the ductile fracture at higher temperatures to the brittle fracture at lower temperatures. The ductile fracture occurs after significant plastic deformation, whereas the brittle fracture occurs with little plastic deformation.

*4 Mesoscopic

A scale used for the evaluation of the characteristics of metals. When characteristics are evaluated based on a grain size of about 10μm or larger, the evaluation range is called macroscopic; when the evaluation is based on the level of atoms or electrons, the range is called microscopic. Mesoscopic refers to the intermediate range between macroscopic and microscopic.

*5 Single roll drive with different diameter rolls

While both upper rolls and lower rolls (having the same diameter) are driven in normal finishing rolling mills, in this method, rolls on one side only are driven in the last three stands; furthermore, the diameters of the upper rolls and lower rolls are different.

*6 Curtain wall cooling systems

Equipment is installed on the outgoing side of the last three stands in order to cool the rolled material. The thickness of the water stream falling on the material is 24 mm or more and the stream forms a wall (laminar flow), providing a high cooling capacity.

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7

Trend of Self-Organization in Materials Research

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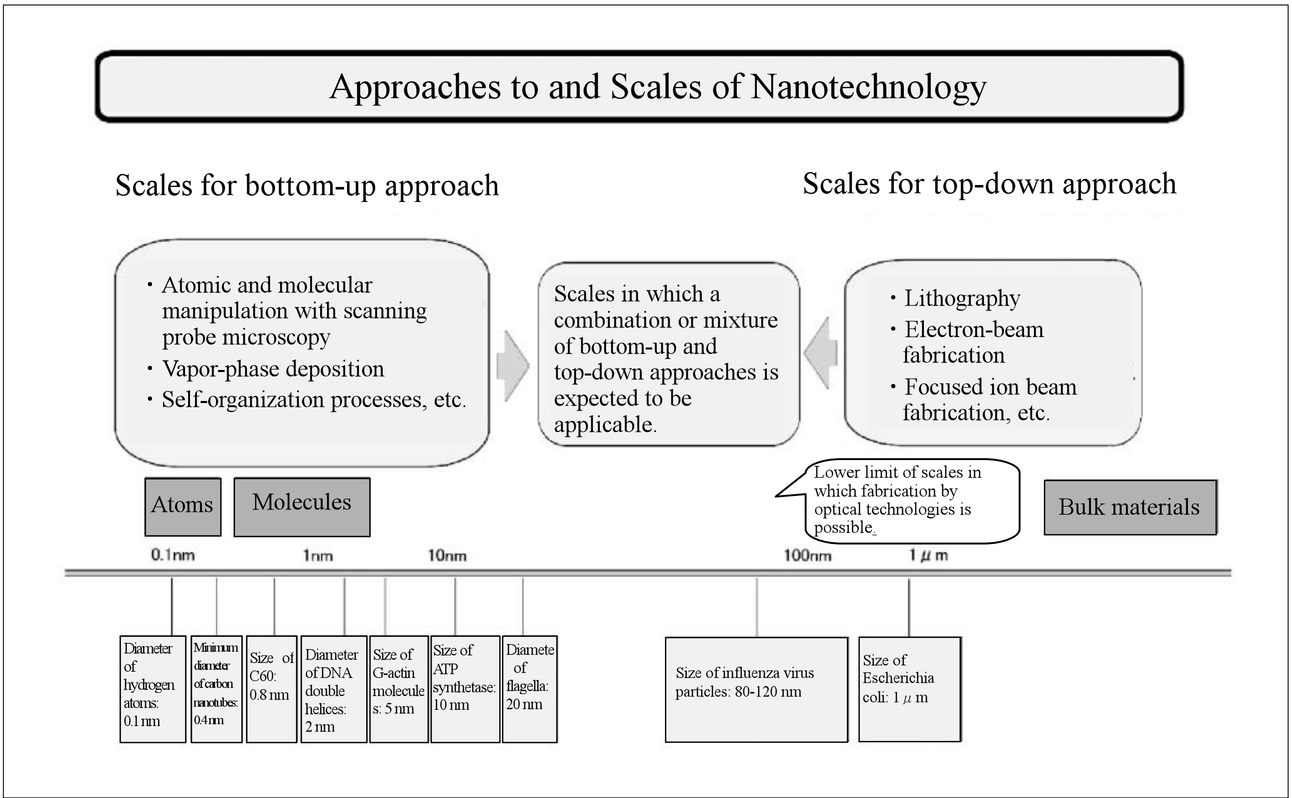
7.1 Introduction

In general, miniaturization of devices provides the advantages of "speeding up," "low power consumption" and "higher integration." Therefore, research on materials on the scale of nanometers (one nanometer is one billionth of a meter: nm) has attracted people's attention. The approach for dealing with such nanometer scale materials can be roughly divided into two categories: One is the "top-down" approach, which carves out a surface as in the case of miniaturization of semiconductors; the other is the "bottom-up" approach, which builds up atoms or molecules into nanometer scale structures (nanostructure). (See Figure 1)

Until recently, nanotechnology has been targeted at semiconductor devices and mainly developed by the "top-down" approach. But researchers in various fields point out that preparation for nanometer scale structures through the top-down approach will face greater difficulties in the near future, i.e., in a few to a few tens of years (these are difficulties associated with technological limitations, physical limitations and economical limitations, but we had to omit the detailed explanation due to space limitations). The bottom-

Figure 1: Approaches to and Scales of Nanotechnology



Source: Authors' compilation by making reference to a report from the Japan Patent Office [http://www.jpo.go.jp/indexj.htm] on investigation into trends in technologies "Related to Nanotechnology and Materials" for which patent applications have been filed up approach has gained the spotlight as a complement or alternative approach to the top-down approach on that account.

This report covers the self-organizing method, which has drawn keen attention among bottom-up approaches, and summarizes goals, present state of self-organized materials researches, and issues to achieve goals.

7.2 Definition and goals of self-organization in materials research

7.2.1 The self-organization method in bottom-up approaches

Among the various bottom-up approaches, which placement should the self-organization method take? In this section, we will explain from which viewpoint the self-organizing method has attracted people's attention by giving an outline of the "atomic or molecular manipulation technique by using the scanning probe microscopy (SPM)".

The atomic or molecular manipulation technique by using SPM refers to the "method of creating artificial structures by pinching atoms or molecules one-by-one with a minute SPM probe and aligning those atoms or molecules at intended positions." Many reports have already been made about the realization, with the use of the manipulation technique, of various characters wrote by aligning atoms (atomic-scale writing) and nanostructure created with atoms. In theory, by applying the manipulation technique, nanostructure with 3 dimensions of a few nanometers (quantum dots) can be produced. And materials with innovative functions realized by quantum dots can be expected to become available.

In practice, however, we may face great difficulties when we try to prepare quantum dots with SPM. Even if the present atomic or molecular manipulation technology (which necessitates about an hour to put together one character by atomic-scale writing) advances, and even if we become able to pick up one atom and place it at an intended position in 1/1000 of a second, we will still need to move about 8,000 atoms in order to assemble a quantum dot measuring about 5 nanometers in diameter. In addition to this, work for about 90 days without a break to align quantum dots on a plane measuring 1/100 mm square. Therefore, preparation of quantum dots with SPM simply cannot be said to be realistic.

Moreover, although atoms can be picked up and moved on a one-by-one basis in the case of substances containing only one kind of element such as silicon, it can be easily expected that greater technological difficulties will arise in the case of manipulation with SPM of compound semiconductor materials composed of two or more kinds of elements such as gallium arsenide (GaAs), which demonstrates superior properties to silicon when used for high-speed transistors. (However, this estimation was developed based on very simplified trial calculations. In reality, high-value-added nanostructure may possibly be prepared by combinations of two or more techniques in the form of, for example, SPM for very small structures and different techniques for larger structures.)

In this section we took manipulation with SPM as an example of the bottom-up approach, it is expected that many problems including considerable time and energy consumption requirements will turn up in other bottom-up approaches, too. In such circumstances, among bottom-up approaches, the "self-organization" method has received attention as the approach that possibly enables the reduction of time and energy needed for the preparation of nanostructure.

7.2.2 What is self-organization?

As mentioned in "Trends in Nanobiology" in the fifth issue (Jan. 2003), no scientific consensus about the concept of "self-organization" itself has been reached by researchers, and there has been no clear definition about it. In this report, we will discuss self-organization by defining it as the "process utilized in the preparation of materials or devices, in which components of materials or devices assemble by themselves to form specific structures (self-assembly), or the process in which components spontaneously form specific patterns (dissipative structures) through energy and matter diffusion."

We give one example of self-assembly here. The formation of a globular structure called micelle, which occurs when soap molecules, having both the hydrophilic group with higher affinity for water and the hydrophobic group with lower affinity for water, are in water with the hydrophilic unit being on the surface and the hydrophobic unit being sequestered inside. On the other hand, we quote "wind patterns on the sand" as one example of dissipative structures. Patterns of the sand on the surface of land exposed to external forces such as wind without being subjected to artificial processes.

So far in this report, we intentionally discussed self-organization in the filed of nanotechnology for the purpose of explaining the reasons for which research on self-organized materials has become a focus of people's attention. However, the concept of self-organization covers processes that vary in their length, from those on very small scales such as the formation of nanostructure to those on very large scales such as the formation of swirling cloud streams associated with overlaying temperature inversion (Karman vortex). Therefore, in the following sections, we will discuss the goals, present state of self-organized materials researches, and issues to achieve goals (bridge the gap between the goals and the present state) without special regard to the length scales of materials.

7.2.3 Goals of self-organized materials research

We authors have reached the conclusion that the goals of self-organized material research at the present stage are the following three (we took into account discussions with some of the researchers named in the "Acknowledgments"):

Goal A:
Precision synthesis of molecular clusters

Goal A sets out to establish technologies that enable the precision synthesis of clusters of atoms or molecules (which can be sometimes components of systems), especially the clusters of molecules and nanostructure that are difficult to prepare when using conventional synthesis methods, by utilizing the functions of atoms or molecules themselves (in a resource-saving and energy-saving manner) as well as to induce innovative functions in materials synthesized in such a manner.

Goal B:
Establishment of patterning and self-aligning technologies

Goal B sets out to establish, irrespective of the physical states (gaseous, liquid and solid state) or scales (nanometer [nm], micrometer [μm], millimeter [mm] , centimeter[cm], and meter [m]) of the components of targeted systems, preparation processes through which useful patterns in the targeted systems can be formed in large quantity at one time by utilizing the functions of components of the systems themselves (in a resource-saving and energy-saving manner). And the preparation of desired structures by self-alignment of components at intended positions with high precision.

Goal C:
Preparation of materials and devices through the self-organization method

Goal C sets out to realize smart materials (also called "intelligent materials," which exercise their functions in response to changes in ambient conditions such as temperature and exposure to light) and molecular devices by creating hierarchical structures in two or more scales by means of, for example, combining the technologies mentioned as Goal A and Goal B and inducing functions characteristic to each hierarchy.

In the rest of this report, we will give, in Chapter 7.3, some examples of research aiming to achieve Goals A to C in order to enhance the readers' understanding of such research, and will discuss, in Chapter 7.4, issues to bridge the gap between Goals A to C (mentioned in this section) and the present state (mentioned in the next section).

7.3 Present state of self-organized material research

In this Chapter, in order to enhance the readers' understanding of the present state of self-organized material research, we will present interesting comments by researchers in Japan who are actively studying such materials, as well as examples of organizational research for self-organized materials, and will compare the different methods for creating the same nanostructure in terms of equipment to be used, the number of steps to be followed, etc. Then, we will cite some examples of research aiming to achieve Goals A to C.

7.3.1 Present state of research in Japan and other countries

Dr. Tomohiko Yamaguchi, chief researcher at the Nanotechnology Research Institute of the National Institute of Advanced Industrial Science and Technology (AIST), an Independent Administrative Institution (IAI) under the Ministry of Economy, Trade and Industry (METI), made the following comment about the “levels of self-organized material research in Japan” and the “alienation between theories and experiments in front-line research.”

(1) Levels of self-organized materials research in Japan

While there has been a growing international trend toward application of the processes of dissipative structure formation to material sciences, it was the polymer (macromolecule) research groups in Japan that set the trend in the mid 1990s.

In addition, with regard to research on metallic nanoparticles, the staff on the Hayashi Ultrafine Particle Project in Japan (a project pursued during the period from 1981 to 1986 within the Exploratory Research for Advanced Technology [ERATO] program administered by the Japan Science and Technology Corporation (JST)) established the method for gas-phase synthesis ahead of all other countries. It has been reported that the Clinton administration in the United States closely examined the fruits of the Hayashi Ultrafine Particle Project, etc., when they investigated the state of nanotechnology research in Japan before announcing the U.S. National Nanotechnology Initiative (NNI) in January 2000. We feel that Japan has been ahead of the rest of the world when it comes to preparation technologies by the mechanism of dissipative structure formation.

(2) Alienation between theories and experiments in front-line research

Examples of collaborative work in Europe done by both theoreticians and experimentalists include close collaborative relationship between the theoretician group lead by Mikhailov, a mathematician, at the Fritz-Haber-Institut der Max-Planck-Gesellschaft, which was established in honor of Haber, who accomplished great achievements in research in chemical engineering including the fixation of atmospheric nitrogen. And the group of many experimentalists lead by Ertl, director of the institute, who is a world authority on solid surface reaction and has received the Kyoto Prize, which leads to theoretical demonstration of the formation of periodic nanostructure in the reaction-diffusion-advection system.

In the United States, a group lead by Karim, who is famous for his research on polymer materials, at the National Institute of Standards and Technology (NIST) has succeeded, in collaboration with theoreticians, in inducing spatially-periodic structures on the surfaces of polymer materials by applying external forces such as an electric field. Moreover, Professor Swinney at the University of Texas in Austin and Professor Showalter at West Virginia University, both of whom are well-known as experimentalists well acquainted with theories in the research fields of self-organization of patterns and non-linear dynamics, seem to frequently exchange ideas with theoreticians.

On the other hand, turning our eyes to situations in Japan, no large trend in research on self-organized materials has been created in Japan in spite of the facts that some researchers in Japan have earned excellent reputation from foreign countries and that such researchers have exchanged ideas with theoreticians for several years. In Japan, theoreticians and experimentalists still pursue self-organized material research separately.

7.3.2 Examples of organizational research for self-organized materials in Japan

In Japan, after the Kunitake Molecular Architecture research project within the Exploratory Research for Advance Technology (ERATO) program, administered by the Research

Development Corporation of Japan (JRDC) (research term: 1987-1992), research on self-organized material has been pursued in the form of projects such as the New Strategic Sectors Decided for Core Research for Evolutional Science and Technology (CREST) "Construction and Functions of Molecular Complex Systems (Total Construction of Energy Conversion and Signal Transduction Systems in Biology)" (research leader: Professor Yoshiaki Kobuke at the Graduate School of Materials Science, Nara Institute of Science and Technology)/ Japan Science and Technology Corporation (JST) (research term: 1998-2003), the Yokoyama Nano-structured Liquid Crystal Project within the ERATO program/JST (research term: 1999-2004), etc.

Furthermore, good results have been obtained including the creation of nanostructure with the self-organization method in collaborative research organizations such as the Joint Research Center for Atom Technology [JRCAT] (centralized joint research organization for the collaboration of industry, academia and government, whose parent organizations include the Angstrom Technology Partnership [ATP] and the Agency of Industrial Science and Technology [AIST]), which has completed a ten-year project begun in April 1992 and ended in March 2002.

Recent movements toward the facilitation of self-organized material research include the establishment of the Nanotechnology Research Center at the Research Institute for Electronic Science, Hokkaido University (director of the center: Professor Masatsugu Shimomura) in April 2002. The center is deemed to be a "facility to develop innovative nanoscience technologies integrating the top-down approach for semiconductor technologies into the bottom-up approach utilizing molecular or atomic self-organization, through interdisciplinary and multidisciplinary research activities, and to play a part in the nanotechnology network in Japan." Expectations are now placed on future achievements produced through research activities at the center.

7.3.3 Comparison between the micro-nano fabrication (miniaturization) technique and the self-organization method in the preparation of materials — Examples of the preparation of honeycomb films

In this section, we will compare two methods for preparation of the same honeycomb film: One is the lithography method, a representative "miniaturization technique"; the other is the "self-organization method" (see Figures 2 and 3).

As you can see from Figures 2 and 3, when you prepare the nanostructure such as honeycomb films, it will be more helpful to utilize the self-organization process for the following reasons:

(i) The self-organization method is more energy- and cost-saving (In the lithography method, it does matter what kind of devices you use, while there is no need for the use of large or high-priced devices when you utilize the self-organization process).

(ii) The self-organization method requires fewer steps and a shorter time (You cannot finish the entire process in one hour by using the lithography technique, but you can finish the entire process in about 30 minutes when utilizing the self-organization method).

(iii) The self-organization method enables you to prepare continuous patterns in a large area.

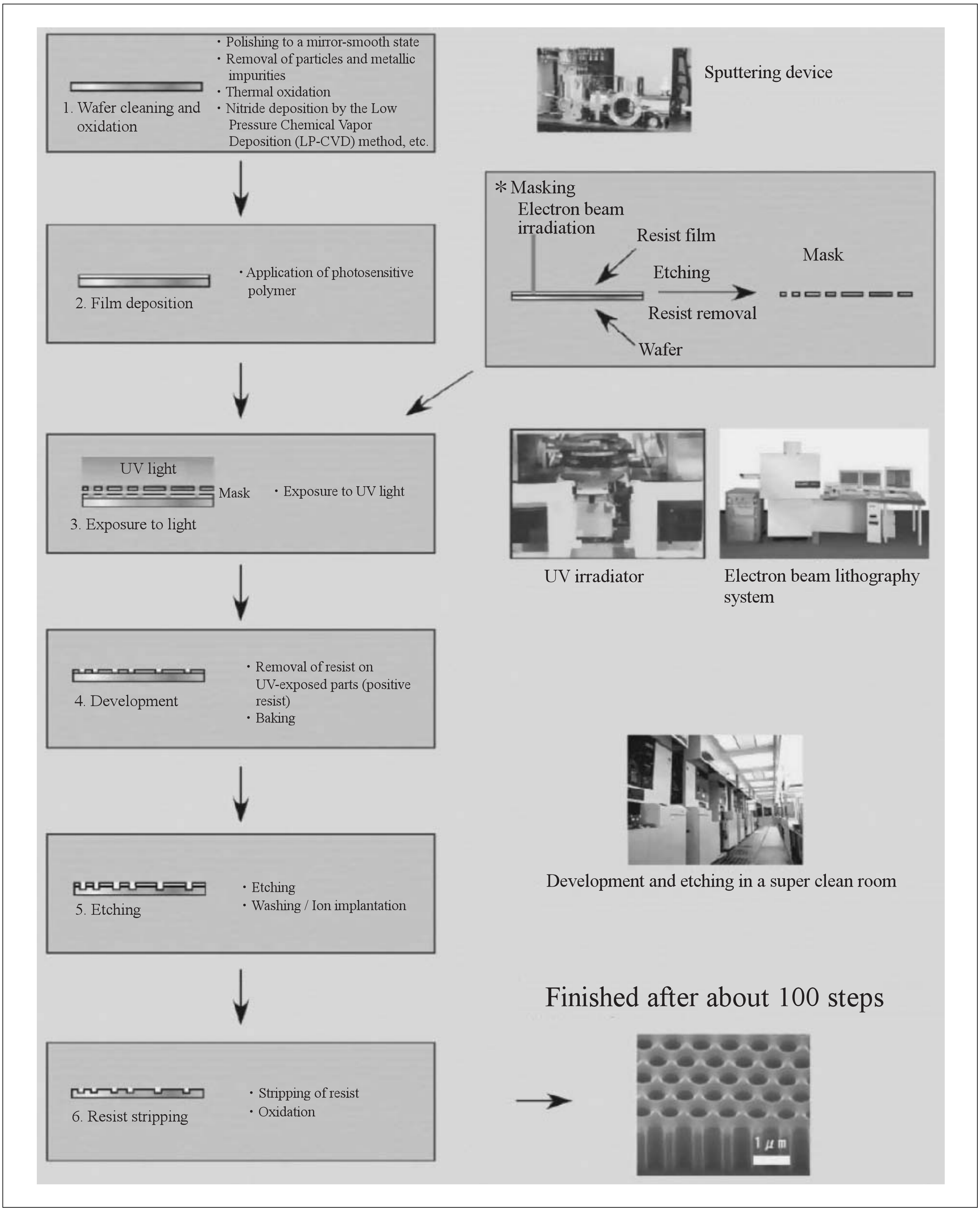
(iv) The self-organization method permits a wider selection of materials to be prepared (Lithography permits only a limited selection of materials like silicon substrate. However you can choose either inorganic or organic substances as materials to be prepared with the self-organization method).

(v) The self-organization method does not require a high degree of engineering skill when you handle devices to be used in the relevant process (The steps of preparation by the self-organization method can be automated).

However, you should take notice that it cannot always be said that preparation with the self-organization method is more advantageous in the production of some structures.

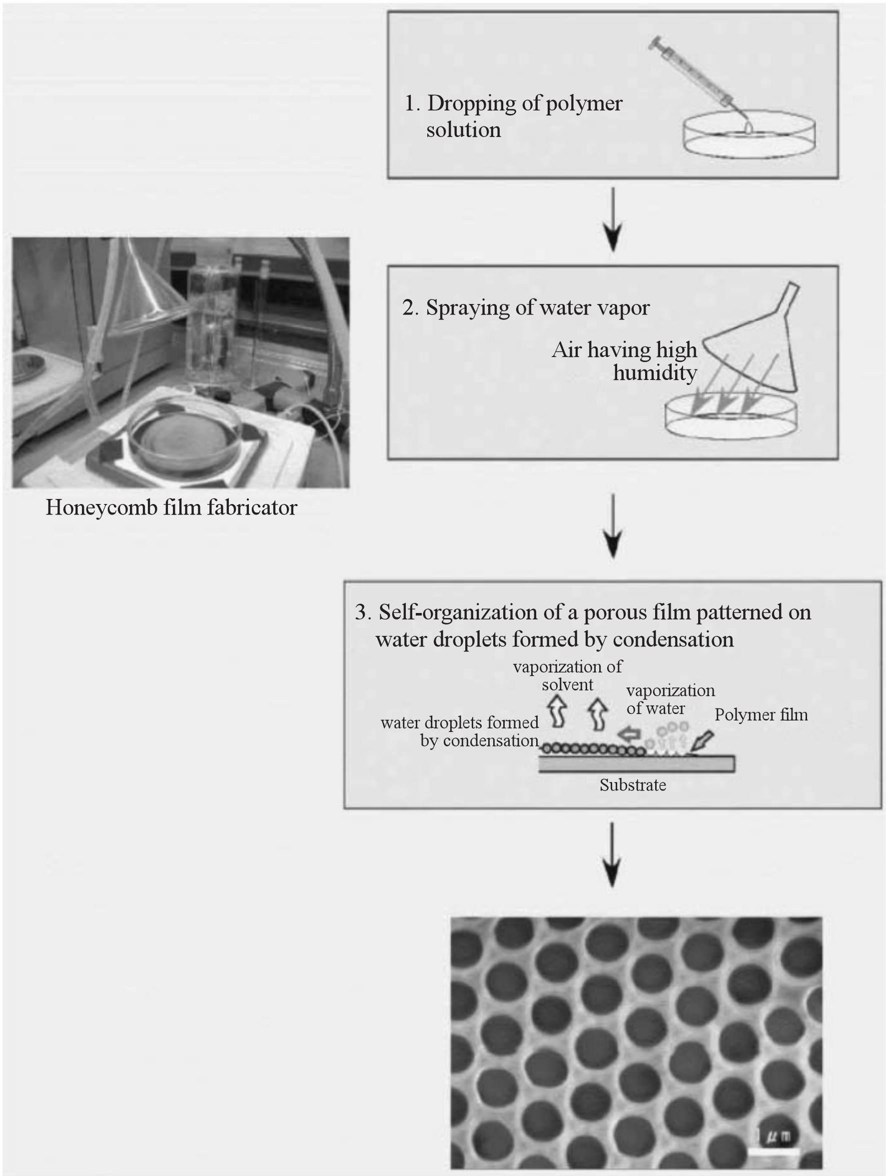
The self-organization process has the following drawbacks: First, it produces "a large environmental load because the method necessitates the use of organic solvents" (but this drawback can be removed if you operate devices in a completely closed system); and second, "it has poor reproducibility" (i.e., it produces errors in places) as opposed to lithography, which allows the production of desired 2-dimensional structures without failure (However, while honeycomb pore sizes show statistical distribution, they are so uniform and regular that they produce a

Figure 2: Preparation Processes for honeycomb films using microfabrication technology.



Source: Authors' compilation by making reference to materials provided by Professor Masatsugu Shimomura, director of the Nanotechnology Research Center, Research Institute for Electronic Science, Hokkaido University

Figure 3: Preparation for honeycomb films through the self-organization process.



Source: Authors' compilation by making reference to materials provided by Professor Masatsugu Shimomura, director of the Nanotechnology Research Center, Research Institute for Electronic Science, Hokkaido University

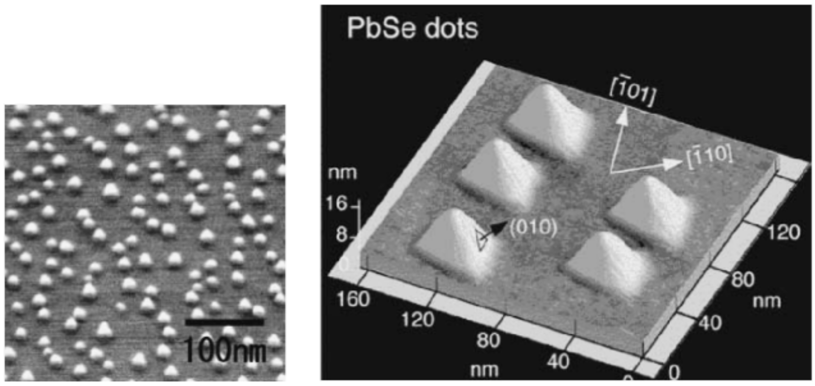
considerable number of high-order diffraction gratings under scattered light. Therefore, under appropriate conditions, almost uniform structures can be fabricated with excellent reproducibility).

7.3.4 Examples of research aiming to achieve Goal A (Precision synthesis of molecular clusters)

(1) Preparation of Compound Semiconductor Quantum Dots

It is expected that quantum-dot-based devices with novel structures will exert innovative functions that cannot be expected from conventional bulk-type semiconductor devices. So far, such devices including power-saving quantum dot lasers that emit strong light by the passage of only a small current have been prepared at the laboratory level, and research on compound semiconductor quantum dots has been pursued with the aim of applying the findings from research to the production of high-density memory devices and advanced telecommunication devices (see Figure 4).

Figure 4: A scanning electron micrograph (SEM) of GaAs quantum dots fabricated on the surface of a GaAs substrate (left); An atomic force micrograph (AFM) of lead selenide (PbSe) quantum dots with pyramidal shape fabricated on the surface of a lead telluride (PbTe) substrate (right).



Source: provided by Nobuyuki Koguchi, affiliated Fellow

Source: October 23 issue of the journal Science [1998; Vol. 282, pp. 734-737].)

(2) Synthesis of molecular clusters, which are extremely difficult to prepare by conventional chemical synthesis

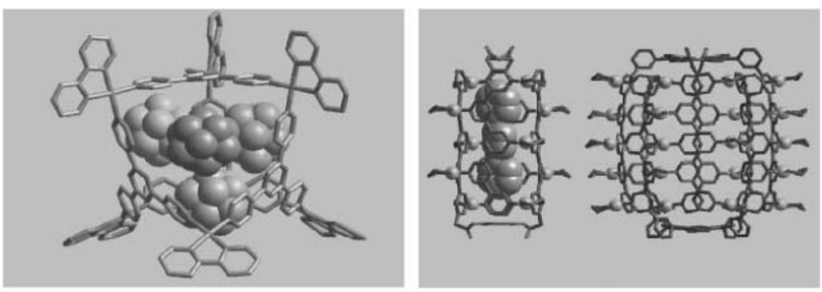
In the biological system, hydrogen bonds are skillfully utilized as the driving force for self-organization. While Professor Makoto Fujita of the Department of Applied Chemistry, Graduate School of Engineering, University of Tokyo, has been spontaneously and quantitatively preparing molecular clusters by utilizing coordinate bond as a driving force. In addition, Professor Fujita found that materials with a 3-dimensionally closed structure as shown in Figure 5 have unique inner space inside their molecular skeletons that is isolated from the outside world, and he considers that molecules incorporated in such materials are expected to have novel properties or chemical reactivity. Therefore, Professor Fujita is now pursuing research on such materials (see Figure 5).

Professor Fujita has analyzed the current state of research on the organization of molecular clusters through self-assembly as follows:

— Since around 1990, marked progress has been seen in research on self-assembly in systems utilizing hydrogen bond or coordinate bond. Unique nanostructure based on ingenious molecular designs have been prepared and reported, including the "tennis ball molecule" that was formed by binding, at the seam of hydrogen bonds, molecules resembling developed tennis balls in shape as well as a "double helical complex" that was formed as two or more metal ions with two molecular strings coiling around them.

— Triggered by our research on compounds such as the "molecular square" (1990) and

Figure 5: Cage structure (measuring about 2 nm in diameter: In this figure, four molecules of carborane (boron-carbon cluster measuring 0.08 nm in diameter) are confined in the cage structure) (left); Tube-shaped capsule structure (measuring about 3 nm in length) and barrel structure (measuring 2 nm and 3 nm in diameter and height, respectively) (right).

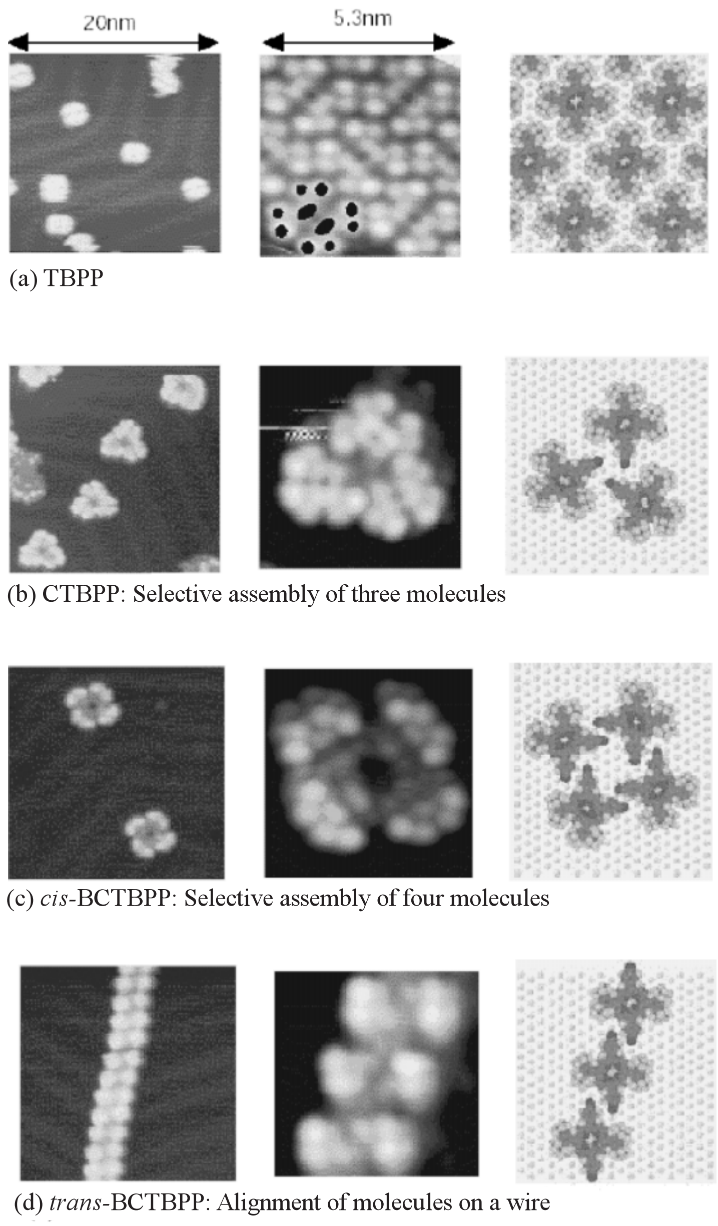


Source: provided by Professor Makoto Fujita of the Department of Applied Chemistry, Graduate School of Engineering, University of Tokyo "molecular regular octahedron" (1995), which we have successfully prepared through self-assembly, research has been actively conducted with the aim of building up various two- or three-dimensional structures into polygons or polyhedrons through self-assembly.

— In our research, we can uniquely and quantitatively self-organize the requested structure by integrating different manners of bonding (directions, forces, and numbers) and variety of molecular designs of organic molecules.

— On the scales of about several nanometers or less, the principles of self-assembly, in which the intermolecular force associated with specific directionality and appropriate binding strength is to be strategically utilized, are about to be established. However, on the scales of several to several tens of

Figure 6: Scanning tunneling micrographs of a porphyrin aggregate (left two columns) and corresponding simulated models used in the consideration before the actual assembly of molecules (right one column).



Source: Website of the National Institute for Materials Science [independent administrative institution]; http://www.nims.go.jp/nims/former/info/press12.pdf nanometers, the principles of self-assembly are far from the establishment.

(3) Control of molecular nanostructure on solid surfaces

Takashi Yokoyama, a researcher in the Nano-Device Research Group at the Nanomaterials Laboratory, National Institute for Materials Science (an independent administrative institution) has shown that direct binding of porphyrin molecules onto solid surfaces is hindered by the addition of the insulating butyl group ($-CH_2CH_2CH_2CH_3$) as a "foot" to those molecules, which is known to be a functional molecule, and has also shown that the addition of the cyano group ($-CN$) as a "hand" enables selective and spontaneous molecule-to-molecule binding. Extensive studies have been conducted on technologies for assembling molecules by utilizing molecular hands, but most of such studies have been done in liquid. Since self-assembly on solid surfaces is a prerequisite for the practical use of such technologies, development by Dr. Yokoyama of technologies for assembling molecules into molecular clusters on solid surfaces has great significance (see Figure 6).

7.3.5 Examples of research aiming to achieve Goal B (Establishment of patterning and self-aligning technologies)

(1) Preparation of dots, wires, lattices, honeycomb structure, etc..., by using polymers and fine nanoparticles

Professor Shimomura, et al. mentioned above (Figures 2 and 3) have succeeded in preparing nanostructure as shown in Figures 7 and 8, by utilizing the "polymer-solution-casting process" in which they cast polymer solution onto the surfaces of substrates and dry them to prepare thin films (A photograph of the honeycomb structure is shown in Figure 3). At present, research is being pursued on technologies for preparing honeycomb films with the aim of applying the technologies to the preparation of photonic crystals having periodic alignments of

Figure 7: Fine particles measuring about 100 nm in diameter embedded into the pores (measuring a few micrometers in diameter) on an e-caprolactone (a biodegradable polymer) honeycomb film as the substrate (left); Liquid crystalline polyacetylene deposited on the mica substrate (provided by Professor Kazuo Akagi, Tsukuba University), which was patterned by Professor Masatsugu Shimomura et al., Hokkaido University (measuring 4μm and 50 nm in width and height, respectively)(right).

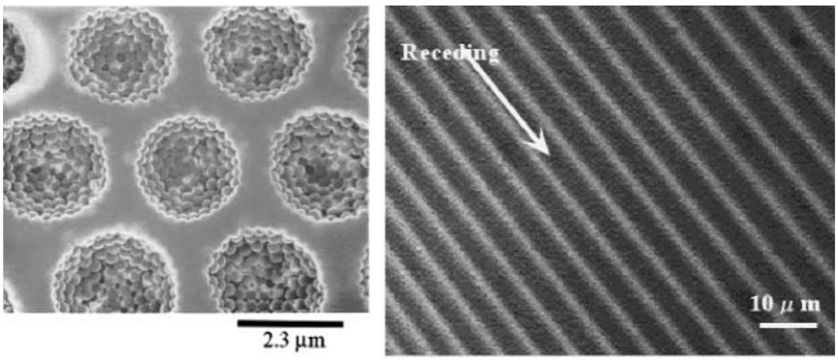
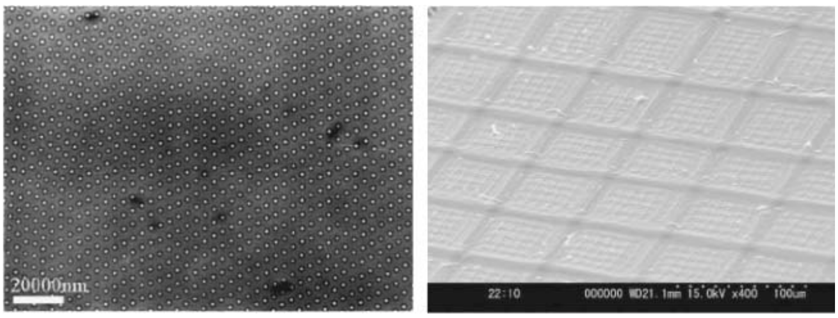


Figure 8: Polystyrene dots measuring 1-2μm and 30 nm in diameter and height, respectively, fabricated on the mica substrate (left); Polystyrene lattice fabricated on a slide (line widths are 5μm and 1μm, and heights are 500 nm and 100 nm.) (right)



unit structure on the scale of light wavelengths (photonic crystals are utilized for the artificial control of light emission and light propagation). In addition, it has been demonstrated that honeycomb films themselves can be used as, for example, the substrate for cell culture.

The "polymer-solution-casting process" is a versatile technique that can be utilized for the patterning of structure independent of the types of materials. Therefore, it is expected that quantum dots and quantum wires (an artificial structure that confines particles carrying electricity on a one-dimensional space [along the anteroposterior axis]) prepared by the technique will contribute to the development of liquid crystal displays and electronic paper (ultra-thin displays that are portable in the rolled-up form) with novel properties (See Figures 7 and 8).

7.3.6 Examples of research aiming to achieve Goal C (Preparation of materials and devices through the self-organization method)

Until now, research aiming to achieve Goal A (Precision synthesis of molecular clusters) and Goal B (Establishment of patterning and self-aligning technologies) has been pursued to some degree. In contrast, research aiming to achieve Goal C (Preparation of materials and devices through the self-organization method) has been conducted with relatively limited success as compared to that of Goals A and B. Therefore, future progress in research for Goal C is being awaited.

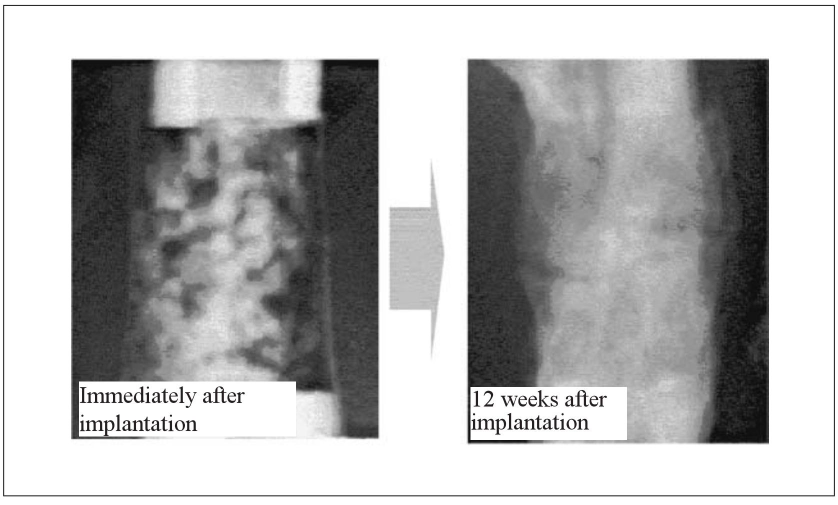
(1) Development of bone-like materials that are to be integrated into the bone metabolism system in vivo

Professor Kenichi Shinomiya at the Graduate School of Tokyo Medical and Dental University and Junzo Tanaka, director and chief researcher at the Biomaterials Center, National Institute for Materials Science (an independent administrative institution) have synthesized bone-like hydroxyapatite/collagen nanocomposites that have a bone-like structure and chemical composition under near-biological conditions (pH 8-9, temperature 40°C). They confirmed that hydroxyapatite crystals (30 nm) and collagen molecules (300 nm) self-organized to form fibers with an overall length of 20μm or more under near-biological conditions (See Figure 9).

(2) Alignment of many nanodevice components on flexible or curved substrates

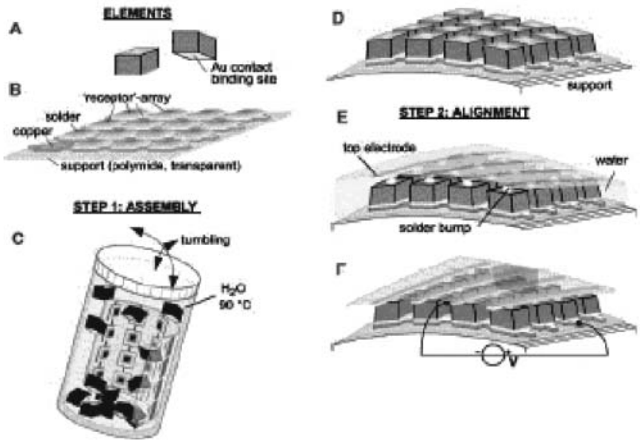
Professor George M. Whitesides has prepared, by utilizing the self-assembly mechanism, a cylindrical display with 113 light-emitting diodes (LED) with a dimension of about 300μm in length. In

Figure 9: Particulate bone-like composite was transplanted into the tibia of a dog (defective part of the tibia measuring 20 mm in length was covered with a bioabsorbable film in order to fix the particles). Twelve weeks after the transplantation, bone tissue at the defective part was almost completely regenerated and the dog regained free mobility.

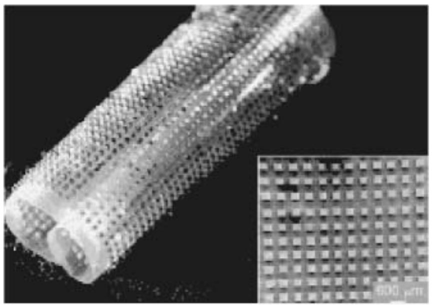


Source: Website of the National Institute for Materials Science [independent administrative institution]; http://www.nims.go.jp/nims/former/info/press11.pdf

Figure 10: When light-emitting diodes (LEDs) covered with gold and copper substrate having solder arrays on its surface were suspended in water having a temperature exceeding the melting point of solder, in such a way as to minimize the free energy of the solder-water interface (A-F); About 1,560 silicon cubes were successfully aligned on the surface of a flexible and curved substrate within 3 minutes (right).



Source: April 12 issue of the journal Science [2002; Vol. 296, pp. 323-325]



Source: April 12 issue of the journal Science [2002; Vol. 296, pp. 323-325], as with the figures on the left

addition, he has succeeded in generating an array containing 1,500 small silicon cubes on an area of 5 square centimeters in less than 3 minutes (See Figure 10).

7.4 Issues to achieve goals (in order to bridge the gap between the goals and the present state)

Primary requirements for the accomplishment of Goal A (Precision synthesis of molecular clusters), Goal B (Establishment of patterning and self-aligning technologies) and Goal C (Preparation of materials and devices through the self-organization method) may need for a deeper understanding of self-assembly, the formation of dissipative structures, and the combination of self-assembly and dissipative structure formation, respectively. And further research for the preparation of practical materials should be promoted through the achievement of Goal C.

7.4.1 Issues to achieve Goal A (Precision synthesis of molecular clusters)

"Intermolecular interaction plays an important role in the self-assembly process, so success in realizing self-organization through self-assembly depends on molecular designs."

The process of self-organization through self-assembly has the advantages that it allows efficient preparation of three-dimensional structure, which is several tens of nanometers or less in size and are difficult to be prepared with the top-down method, and that it permits, once molecular design is properly developed, the precise preparation of three-dimensional structure with minimum energy. However, even when you want to apply a combination of some principles of self-assembly to the process of materials with intended structure, almost no such principles have been discovered as yet. In order to develop the self-organization method through the self-assembly, it is imperative to deepen the understanding of the principles in self-assembly by pursuing research on the control of intermolecular forces such as hydrogen bonds and coordinate bonds and to establish technologies for preparing desired materials for practical use by applying a combination of some of those principles.

Professor Nobuo Kimizuka at the Department of Applied Chemistry, Graduate School of Engineering, Kyushu University said, "From now on, simple preparation of nanostructure will not be enough, and it will be increasingly significant to design molecular structure with electronic states that may realize the exertion of innovative functions and to prepare such structures through the self-assembly mechanisms."

7.4.2 Issues to achieve Goal B (Establishment of patterning and self-aligning technologies)

"When you intend to create specific dissipative structures, you need to take into account not only molecular designs but also the environment around the molecules (external systems). In designing the external systems, you should establish methods for quantitatively evaluating the flows of energy and entropy through the relevant molecules and associated external systems, then discover principles in the designing of appropriate external systems that permit the desired patterning and periodicity of the relevant molecules, and develop technologies that allow the application of those principles to the relevant molecules and external systems."

In order to enhance the readers' understanding of flows of energy and entropy through systems, here we cite crystal growth as an example. Crystal growth is the process during which crystalline substances in solution (raw material) is transformed into solid crystals, and has very great significance in the preparation of various materials. In order to acquire crystals with intended thickness, composition, shape and quality (in terms of defect density, etc.), it is necessary to control; the temperature during the growth process, supply system for raw materials, degree of supercooling or oversaturation, etc. While the necessity for control of these factors has been empirically well recognized, such control exactly corresponds to the external system control for the control of the flows of energy and entropy through the system. In light of the case of crystal growth cited here, in order to establish a method for self-organization through the mechanism of dissipative structure formation, it may be necessary to pursue research on elementary processes (in cases where complex phenomena occurring in the system containing a large number of particles can be seen as an assembly of simpler phenomena occurring among a smaller number of particles, the phenomena among the smaller number of particles is called the "elementary process") from the viewpoint of the flows of energy and entropy.

7.4.3 Issues to achieve Goal C (Preparation of materials and devices through the self-organization method)

Issues to achieve Goal C are "to prepare desired materials and devices through the formation of dissipative structures by utilizing structure and parts (components) prepared through the self-assembly mechanism and to prepare desired materials and devices by inducing the self-organization of the components prepared through the self-assembly mechanism."

As mentioned in section 7.3.4-(1), power-saving quantum dot lasers that emit strong light by the passage of only a small current have been prepared at the laboratory level, and great achievements have been yielded in various research fields of nanotechnology. However, as of now, it is not possible to prepare devices with complex structure for practical use through the self-organization mechanism. The most realistic approach as of now may be as follows: First, create clusters of atoms or molecules through the self-organization of those atoms or molecules; and then, build up various atomic or molecular clusters into hierarchical structure in accordance with their scales to create the desired materials or devices.

7.5 Conclusions

So far in this report, we have summarized and described our views regarding the goals and present state of self-organized material research as well as issues to achieve such goals. As stated, in order to prepare various nanostructure, it is highly significant to develop not only conventional nanopreparation techniques but also techniques utilizing the self-organization method.

Furthermore, if the self-organization method becomes applicable to the preparation of materials and devices, which are now created by other methods, it may greatly contribute to resource saving and energy conservation and, further, to environmental protection. In this context, progress in self-organized material research is expected by researchers not only in the filed of nanotechnology but also from a wide variety of areas. We propose in the following paragraphs two issues to facilitate progress in self-organized material research.

(1) Collaboration between theoreticians and experimentalists targeting the establishment of technologies for molecular designing, etc.

In order to develop the self-organization method from this day forward, it will be necessary to further promote research activities aiming to attain the above-mentioned Goal A (Precision synthesis of molecular clusters) and Goal B (Establishment of patterning and self-aligning Technologies).

In self-organized material research conducted in the United States and European countries, good results have been yielded through collaboration between theoreticians and experimentalists. In contrast, no such research environment has been created in Japan. Improvement in this respect may be important for Japan to make further progress and to constantly stay ahead of other countries in self-organized material research.

With regard to the clarification of principles of self-organization, participation of theoreticians in various fields is necessary because dominating laws of systems are scale-dependent. (For example, quantum effects become obvious on the scales of 30 nm or less.) The same holds true for experimentalists. One of the specific measures enables collaboration between theoreticians and experimentalists is to secure human resources to serve as an interface between such theoreticians and experimentalists. Here, human resources as an interface mean people who act as an intermediary between theoreticians and experimentalists by, for example, analyzing the relationship between theories that have been elaborated after the simplification of various conditions and experiments, which have been actually conducted to verify the theories, and by notifying researchers about the findings from such analyses in the form of feedback. Therefore, the people to serve as an interface should have the peculiar aptitude for such work.

It is not necessarily easy to secure human resources having such special aptitude. One possible practical measure to secure such human resources may be, when organizing a project of research through the approaches proposed in the following sections, the specification of functions to be served by people as an interface and to assign the role as an interface to researchers participating in the relevant research project.

(2) Promotion of multidisciplinary and comprehensive research with clear objectives

In order to realize the application of the self-organization method to techniques for the mass production of materials, devices, etc., we must attain Goal C (Preparation of materials and devices through the self-organization method) mentioned earlier in this report. In order to develop technologies for preparing complex three-dimensional structures by hierarchically building up atomic or molecular clusters, cooperation from researchers in a wide variety of fields including mathematics, physics, chemistry, biology, material engineering and mechanical engineering is required in addition to collaboration between theoreticians and experimentalists discussed in the preceding section. Moreover, with an eye toward practical application of technologies developed, it is imperative for researchers and engineers in the industrial community to participate in such research activities.

As of now, however, concepts regarding self-organization vary in accordance with the field, and the sense of mission in research activities is not always shared among researchers. One possible means of tapping into the collective wisdom of researchers in various fields or organizations to promote research on self-organization may be the implementation of a "multidisciplinary and comprehensive research project with clear objectives."

As the first step to implement such a project, you need to set forth such an objective that gives a concrete image to everyone and for which increase in technological levels is essential, as "preparation of a computer in a beaker," and gather experts whose involvement is necessary for the achievement of the objective as well as researchers in a wide variety of fields who are interested in achieving the objective. As the second step, you need to specify issues to achieve the objective. Specifically speaking, issues to be handled to achieve the above objective may, as an example, include the development and preparation of (i) structures that are analogous to transistors, (ii) structure analogous to circuitry, and (iii) structure analogous to a central processing unit (CPU) (architecture). Moreover, in promoting a research project, it may be necessary to clarify the roles and responsibilities to be taken by research groups and researchers intending to address these issues.

Acknowledgments

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8

New Development in MEMS Research
— Technical and Social Aspects —

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8.1 Introduction

MEMSs (Micro Electro-Mechanical Systems) are defined as micro mechanical systems including the movable parts produced by utilizing the processing technology that has been accumulated through the development of semiconductors.

Not only in the United States and European countries that are advanced in MEMS technology but also in Asian countries such as Taiwan and Singapore with aids by governments, there is a strong trend to develop MEMS technology as a new core technology of industry. Currently, the targets of MEMS research cover a wide range of application fields including, in addition to machine parts, medical- and bio-related technologies and energy storage technology [1-4]. Products that are manufactured utilizing MEMS technology are basically characterized by small-lot production of a wide variety of goods, and the technology is expected to activate the development of industry including the creation of venture businesses. Since overseas countries are directing their efforts toward the development of MEMS technology that may endanger the future of the parts supply industry, which has been the specialty of Japan, we cannot take a wait-and-see attitude.

In this report, we will review the history and highlights of MEMS research in Japan, and point out problems in the present research system in Japan.

8.2 What is MEMS?

8.2.1 Typical MEMS devices

One of the typical MEMS products is the Digital Micro Mirror Device (DMD™) (see Figure 1) [1-4].

Figure 1: Optical element with mirrors rotated by electrical voltage. Digital Micro Miller Device (DMD™) [1]

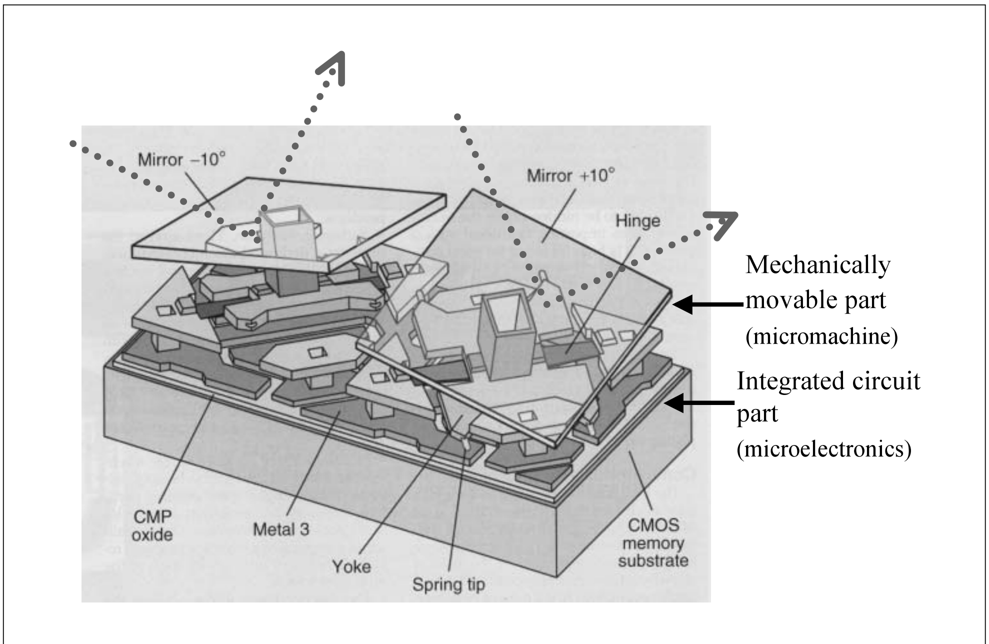
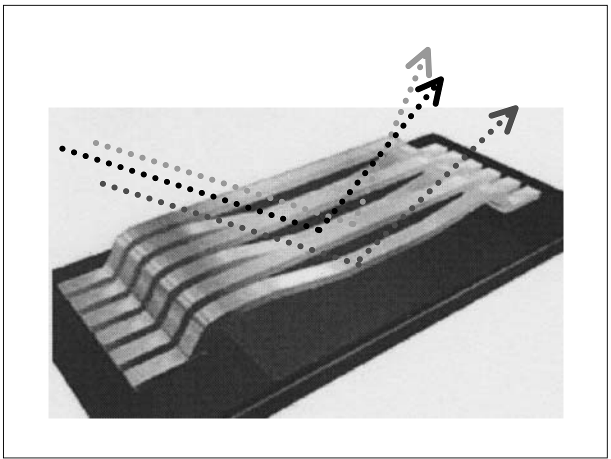


Figure 2: Optical element in which ribbons sink alternately by electrical voltage. Glating Light Valve (GLV) [5]



This is an array of more than a million small aluminum mirrors. Each mirror is 16 μm-square, which is arranged on a silicon integrated circuit. It rotates within the range of ±10 degrees, with a response speed of 1 microsecond. This means that micro machine technology is being placed on microelectronics technology. It gives an advantage that a large number of chips can be formed on a single wafer.

Another example of MEMS devices is GLV (Glating Light Valve), which aims at a display similar to the DMD array (see Figure 2)[5]. This device is made of 1,080 sets of six nitride ribbons (3 μm W × 100 μm L) coated with aluminum. Each set corresponds to a picture element. The laser beams are reflected by the alternate sinking motion of the ribbon caused by an electrical voltage sent from the integrated circuit. It is said that the GLV device could operate 1,000 times faster than the DMD array. It is also produced by making use of semiconductor processing technology.

The present research on MEMS technology is not restricted to such optical devices and covers a wide range of applications (see Table 1) [6].

8.2.2 Definition and historical background of MEMS

"MEMS" is a term that has been used mainly in

Table 1: Applications of MEMS (Underlined applications are especially promising)

Information and communication — Printing: ink jet printer head, etc. — Optical devices: optical switch, display (DMD, FED, etc.), optical scanner, optical modulator, optical connector, variable wave length filter, spectrometer (environmental measurement, etc.), variable focal length lens, mirror, lens array, variable wave length laser, optical detector, free space integrated optical system, micro-encoder, tip sensor for optical fiber, etc. — Electronic devices: high frequency devices (resonator, variable capacitor, inductor, submillimeter wave zone resonator, array antenna, etc.), micro magnetic devices (micro-transformer, etc.), micro relay, mounting parts such as connectors, etc. — Recording: recording head (magnetic, optical, magnetic optical, thermal, etc.), actuator for tracking, etc.
Automobiles, consumer products and environment — Inertial measuring units: acceleration sensor, (automobile use such as with air bags, pace maker, games, seismometer, etc.), gyro (automobile use such as with the brake system, camera shake prevention, motion control, etc.) — Pressure measuring units: pressure sensor (automobile use, medical use, industrial use, etc.) — Other sensors: thermal sensors such as thermal type infrared imager, microphone, ultrasonic transducer, environmental sensing, infrared gas sensor, spatial localization cognition sensor, personal identification sensor (fingerprint, etc.), and others.
Medical and biological — Biochemical: biochemical analysis on chip (DNA chip, capillary electrophoresis, etc.), dispersoid analysis on chip (flow cytometer, etc.), micro reactor (reagent synthesis, etc.), tools for biotechnology (cell fusion, etc.), and others. — Medical care: minimally invasive operations (catheter, endoscope, drug delivery, etc.), embedded devices (artificial internal ear, telemeter, etc.), interfaces to organisms (electrode, probes for sampling and injection), etc.
Production and inspection — Micro fluid: micro valve/pump, flow sensor/controller, etc. — Micro probes: scanning probe microscope (AFM, SNOM, etc.), micro-prober, etc. — Local thermal control: micro cooler, micro heater, micro-calorimetry, thermal actuator, etc. — Energy and resource saving: maintenance tool, active fluid control, micro factory, space applications (micro thruster, micro spaceship artificial satellite, devices for space experiments), etc. — Micro structures: mask for X-ray exposure, collimator for X-rays, shadow mask, electron and particle beam sources, electron and ion beam control, channel plate, micro tool, micro turbine, injection nozzle, etc. — Micro motor/actuator: electrostatic, electromagnetic, piezoelectric, etc. — Micro energy sources: micro fuel cell, micro engine generator, etc.

(According to Professor Esashi of Tohoku University) [6] the United States, and "MST" (Micro System Technology) has been used in Europe, whereas the term "Micromachine" has been used in Japan [7]. The definition of MEMS varies from person to person, and it is still under discussion how far MEMS technology covers the application fields.

It is said that the research on MEMS originated at the School of Electrical Engineering of Stanford University in around 1970. In those days, the results of research on pressure sensors and gas chromatographs, though not so miniature, made on silicon wafers were reported. The research and development of gas chromatographs was commissioned by NASA (National Aeronautics and Space Administration) with the intent of reducing the size in order to be mounted on spaceships. In the latter half of the 1980s, research into creating a new concept, "systems including micro movable parts," was carried out extensively at Berkley Campus of the University of California and Bell Laboratories by combining micromachines, microelectronic devices and sensors, making use of semiconductor technology that was rapidly being developed. The term MEMS was used as a general expression for these research activities. In 1992, a MEMS program was started with the support of DARPA (Defense Advanced Research Project Agency)[8]. The most successful example in the early stage of the program is the above-mentioned DMD™ developed by Texas Instruments (see Figure 1)[9]. Because the mirrors could reflect very strong light and made it possible to provide a large screen display using a small gadget that could not be realized with a liquid crystal display, small-size projectors using DMD devices monopolized the market for a while.

In Japan, micromachine technology represented by microminiature motors attracted attention from 1985, and the Agency of Industrial Science and Technology of the former Ministry of International Trade and Industry started a ten-year big project from fiscal 1991 under the Industrial Science and Technology Development Program. The four themes that have been announced as successful results of this project by the Micromachine Center are: prototype system for in-pipe self propelled environment recognition, prototype system for external inspection of a group of small tubes, prototype system for internal work inside equipment, and prototype system for a micro factory; each of which is a micromachine in the order of mm size [10]. Although none of the systems has been commercialized yet, elemental technologies of each system have continuously been developed in the industry.

8.3 Main points in the research and development of MEMS

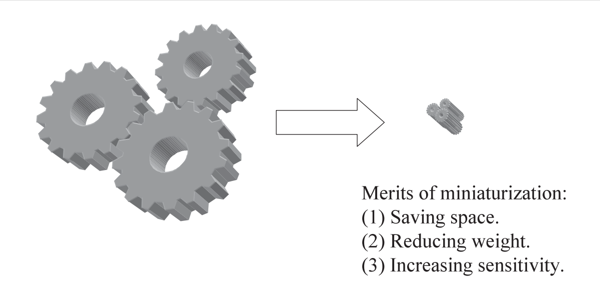
8.3.1 *Characteristics of the research and development of MEMS*

One of the characteristics of the research and development of MEMS is that the results of the research are very close to commercial products. Therefore, even when the research is carried out at an educational institution, not only the ability to solve a problem as pure science is essential but also the attitude when launching a venture business is required. The research and development of MEMS consists basically of three stages: conceptualization, design, and embodiment (prototyping). And the target of research and development cannot be achieved without passing through all of these stages. The outline of each stage is described below.

8.3.2 *Conceptualization stage*

Researchers must begin with the discussion "what type of system can be created by miniaturizing particular movable parts." The very beginning of the concept of micromachines was the question, "what can be created if machines of human size are reduced to the size of silicon chips?" or "what will happen if the machines we use daily are reduced to the size of insects?" At lectures on MEMS relating to biotechnology, the film "Fantastic Voyage," which was put on the screen in the latter half of the 1960s, is always introduced. It is also said that the ultimate target of a sensor is "to realize each function in the living organisms on the silicon chips." It is a very interesting concept to replace biological systems with equivalent circuits. Therefore, it is necessary for the researchers at the beginning of the research to discuss from not only the viewpoint of mechanical engineering and biology but also from the viewpoint of energy and social issues.

Figure 3: Subjects requiring miniaturization are good target in the MEMS research



Consequently, in the research of MEMS, subjects requiring miniaturization are good targets (see Figure 3). Three significant merits of miniaturization are:

1. Saving space.
2. Reducing weight.
3. Increasing sensitivity.

Miniaturization enables the installation or movability of electromechanical systems in a limited space such as in a narrow mechanical space or living organisms. As a result, the following effects are expected [4]:

1. Electrical, optical, and heat energy can be converted to mechanical displacement or high-speed motion.
2. Low electric power consumption can be targeted.
3. Multiple functions can be integrated.
4. Very small amounts of material resources are required.

Although the mechanical strength of silicon single crystal is rarely discussed in the processing of semiconductor devices, it possesses excellent mechanical properties. The micromachines can utilize such properties of silicon single crystal, which cannot be realized with bulk silicon.

Key points for the new system conception are where these advantages are made a good use of and how much flexible idea is taken up (see Figure 4). As can be understood by observing the diversity of living organisms, problems can be solved in multiple ways.

In some cases, it is more significant to integrate technologies of different fields, that is, to integrate mechanical parts, electric circuits, and chemical reaction parts on one chip, than to miniaturize a single function. In such a case of integration, it is of no use to make one function much superior to the other functions, not to mention that the worst part determines the overall performance. This is a very important point when trying to increase the speed and sensitivity of the total system.

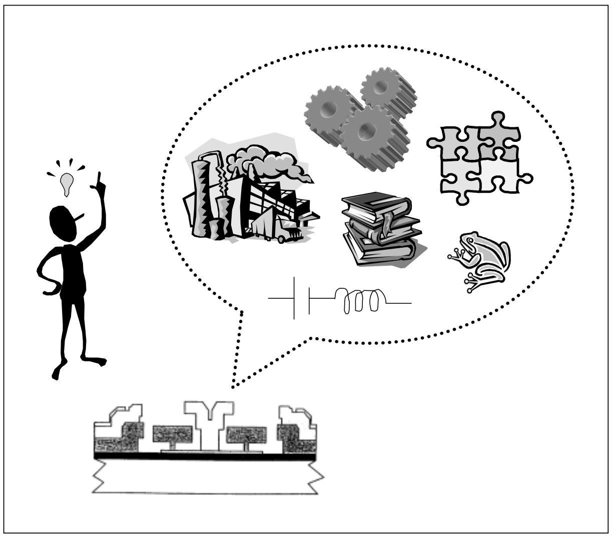
8.3.3 Design stage

After the concept of research is fixed, the total design technology is required for the next stage. Designing capability and simulation technology are required including the mechanical calculation, electric circuit design, and the designing of the silicon fabrication process. Recently, design tools for MEMS have become available even in Japan [11]. And there is also a system that assists in the designing as an activity of scientific society [12]. However, it is true that comprehensive design capability of researchers is attained only through their experience.

For the mechanical calculation in smaller world by four to seven orders of magnitude than the size of human beings, the following requirements must be carefully considered. If these requirements are fully satisfied in the designing stage, noticeable effects will be obtained. [4]

1. Large electrostatic force: in a micro system in which the ratio of surface area to weight is relatively large, the form of the accumulation of usable energy is different. For example, electrostatic motors have an advantage for

Figure 4: Various systems are realized on silicon wafers using semiconductor fabrication technology.



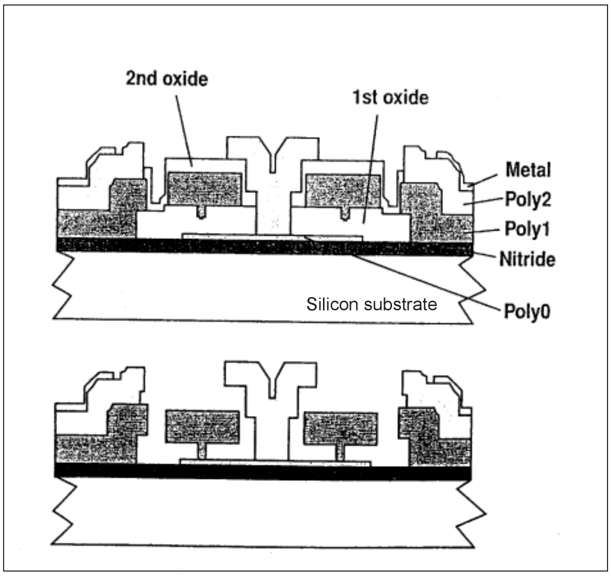
micro actuators from the viewpoint of accumulation capacity, whereas electromagnetic motors are widely used in our daily environments.

2. Small thermal time constant: sensitivity to heat is quite high in micro systems. Therefore, it is possible to produce thermal stress and local thermal change at a high speed making use of this characteristic.
3. Intermolecular and interatomic interaction cannot be neglected: interatomic attraction force (van der Waals force) is more dominant than the gravitational acceleration by the earth.
4. High sensitivity: relatively small changes in physical and chemical properties, such as piezoelectricity, crystal phase change, and chemical reaction in solution, can be utilized by converting them into mechanical displacement.

Even in the design stage, there can be multiple solutions for a single target. For example, there are several types of ink jet printer heads that are typical MEMS parts. All of them inject ink particles of 10 to 30 μm with an energy between 0.5 to 10 mW at intervals of several microseconds and at a high speed of between 5 and 20 m/sec. The dot size is less than $0.2mm^2$. However, several principles of operation are applied including electrostatically driven heads utilizing electrostatic force, bubble jet heads utilizing thermal response, and piezoelectric heads utilizing piezoelectricity. All of which provide high-resolution images [1-4].

Although most of the MEMS products rely on processing technologies that have been developed in the semiconductor manufacturing industry, the technology for MEMS differs from that of semiconductors in that the former requires three-dimensional shapes. In semiconductor integrated circuit technology, patterns are formed on thin films by lithography (a processing technology based on a photo printing method) and these patterns are stacked layer by layer, in which a three-dimensional arrangement is performed, so to speak, by repeating two-dimensional processing. In MEMS technology, on the other hand, patterning with high aspect ratios (height-to-width ratio) is applied providing three-dimensional, movable parts. To realize this, it is necessary to reconsider the technologies that have been neglected in the development of the miniaturization technology for integrated circuits, such as thick film formation and isotropic chemical etching (see Figure 5). It is also necessary to develop equipment again for these processes. In addition, different materials and processes than those used in integrated circuit technology, in which impurities must be strictly avoided, may be used. For example, organic materials may be laminated or mechanisms for flowing chemicals may be provided on the surface of silicon chips. Although there is a move to assign old-generation semiconductor plants for the research and development of MEMS, it must be remembered that success cannot be expected without some new investment and a flexible attitude for the development.

Figure 5: Three-dimensional formation using thick film technology and deep etching technology [2]



8.3.4 Embodiment (trial manufacturing) stage

The trial manufacturing stage follows the design stage. In MEMS technology, successful prototype products are very likely to be developed directly into commercial products, and many trial manufacturing fabs can be converted into commercial production fabs as they are. Therefore, research and development of MEMS is an appropriate theme for cooperative work between industry and academia. Generally speaking, research and development relating to hardware requires more initial investment compared with that of software. The mass production requires still more investment. So it has been difficult to start a venture business in hardware. In the research and development of MEMS, however, it is very possible to connect the results of trial manufacturing directly to the startup of business. In Europe and the United States, most of the research works at this stage are often carried out by outsourcing; also in Japan, it seems to be effective for research organizations that do not have their own trial manufacturing fabs to utilize the facilities of universities provided with ample equipment for common use or private foundries (contracted manufacturing).

8.4 Promising fields for MEMS in the future

8.4.1 Sensors and optical MEMS

Japan has been considered to be in the leading position in the world in the research and development of micro sensors. Japan's advantage over foreign countries in this field could be maintained by effectively promoting cooperation within and between private companies [13]. MEMS in the optical industry is specifically called Micro Optical Electro-Mechanical System (MOEMS). The development of switches for optical communication are attracting attention, in addition to the elements for conventional optical sensors and displays. The research and development works in this field will be extensively carried out mainly in private companies.

Except in these fields, however, it is very difficult at present even to realize trial manufacturing for other applications as described below.

8.4.2 Medical and biological MEMS

In the field of medical and biological MEMS, the size of the market for individual products is rather small. The difficult silicon processing technology is not necessarily required. For this reason, it seems to be possible even in Japan, where the development structures for MEMS are not yet established, to realize small scale production within a short period of time by making use of the small-scale facilities of universities and other public institutions. Therefore, venture businesses are most likely to start in this field. While it is a usual practice in the United States that facilities of universities are used for the research work of private companies, this is not usual in Japan. The reason is because, in many cases, cooperation between universities and private companies has been made by commissioning research to universities through the donation of funds, with the mass production developments done by private companies. In other countries, "Spin-in" is the term used when private companies use the facilities of universities and public institutions. In the medical and biological field, utilization of "Spin-in" including with the production stage seems to be effective because production tends to be in small-lots of a wide variety.

8.4.3 RF MEMS

In the field of RF MEMS (High Frequency MEMS for communication devices), on the other hand, the keyword is "Integration" and the accumulated technologies of semiconductor production can be utilized most effectively (see Figure 6).

Presently, it is said that the domestic semiconductor industry has entered a structural recession. And everyone is changing the lean-to-memories strategy to the production of so-called "System LSIs" in which even passive elements such as capacitors and resistors are integrated into chips. By integrating everything into one chip, the wiring length is reduced and improvement in the Q value, a factor indicating speed-up, is expected. This concept of integration is called SoC (System on Chip). Because even movable parts such as resonator and power supply circuits will be integrated into one chip or one package [14], this may be considered as the stage that follows SoC [3]. It may not be commercially profitable to integrate

Figure 6: MEMS chips arranged on a silicon wafer [1]

movable parts into one chip due to the complexity of processing, increased number of processes, process contamination (contamination by impurities), etc. Therefore, it may be effective at the initial stage to add MEMS parts to other SoC chips or to package multiple parts in one package. In such a case, the products are called SiP (System in Package) rather than SoC.

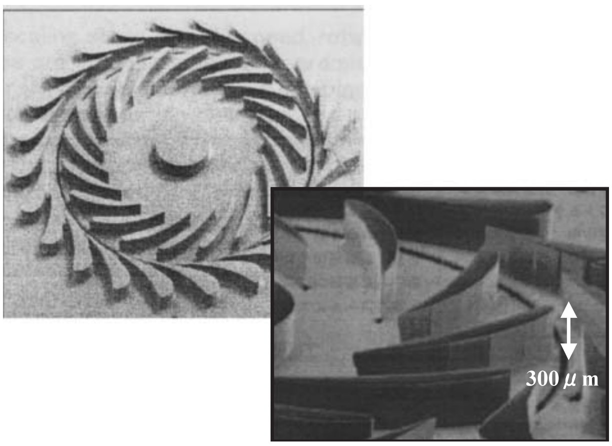
Although RF MEMS is not yet in the stage of practical applications, foundries in Taiwan are paying close attention to the advances because the market is expected to be very large. If large scale of manufacturing of RF MEMS would be realized, some of the discrete parts would become obsolete and bring about a serious crisis in the parts supply industry, which has been the specialty of Japan. Therefore, the Japanese semiconductor industry, which is aiming at the field of system LSI, must take action immediately including patenting activities in the field of RF MEMS, which is an extension of system LSI. Otherwise, Japan's international competitiveness would be lost in this market.

8.4.4 Power MEMS

Research on micro power sources is also a matter of international concern. Workshop "Power MEMS 2002" was held at the Tsukuba International Conference Hall on November 12 to 13, 2002, where prominent researchers in this field gathered. Among the topics of the conference were: miniature combustion electricity generator; micro fuel cell; miniature fuel reformer; and thermoelectric transducer [15].

A miniature combustion electricity generator (see Figure 7) was developed at the Massachusetts Institute of Technology [16], which is a gas turbine produced by deep etching (Reactive Ion Etching) of silicon to form turbine blades of the order of μm, and the blades are rotated at a speed of a million revolutions per minute or higher to generate electric power.

Figure 7: Micro turbine [16]



The micro fuel cell is a miniature fuel cell that is further downsized from the one that is being developed for portable devices at present. It is considered as a possible replacement for lithium cells, whose efficiency is as low as several percent. Great expectation is applied to the microminiature cells produced by MEMS technology, which have a longer life than conventional cells, because they will enable the continuously connection of cellular phones to the Internet. There is also an attempt to realize MEMS engines that use gasoline stored in a cartridge [17]. Such engines will replace the cells for portable tools such as drills and saws, because present cells cannot supply enough power. For these applications that require high heat resistance, silicon carbide (SiC) would be used instead of silicon, or SiC would be coated on the surface. For portable device applications, there is a new concept that fuel is supplied by changing cartridges that are sold at convenience stores.

Although developing the field of power MEMS is a target that is difficult to complete, it is one of the most promising fields due to its expected market size and impact on society.

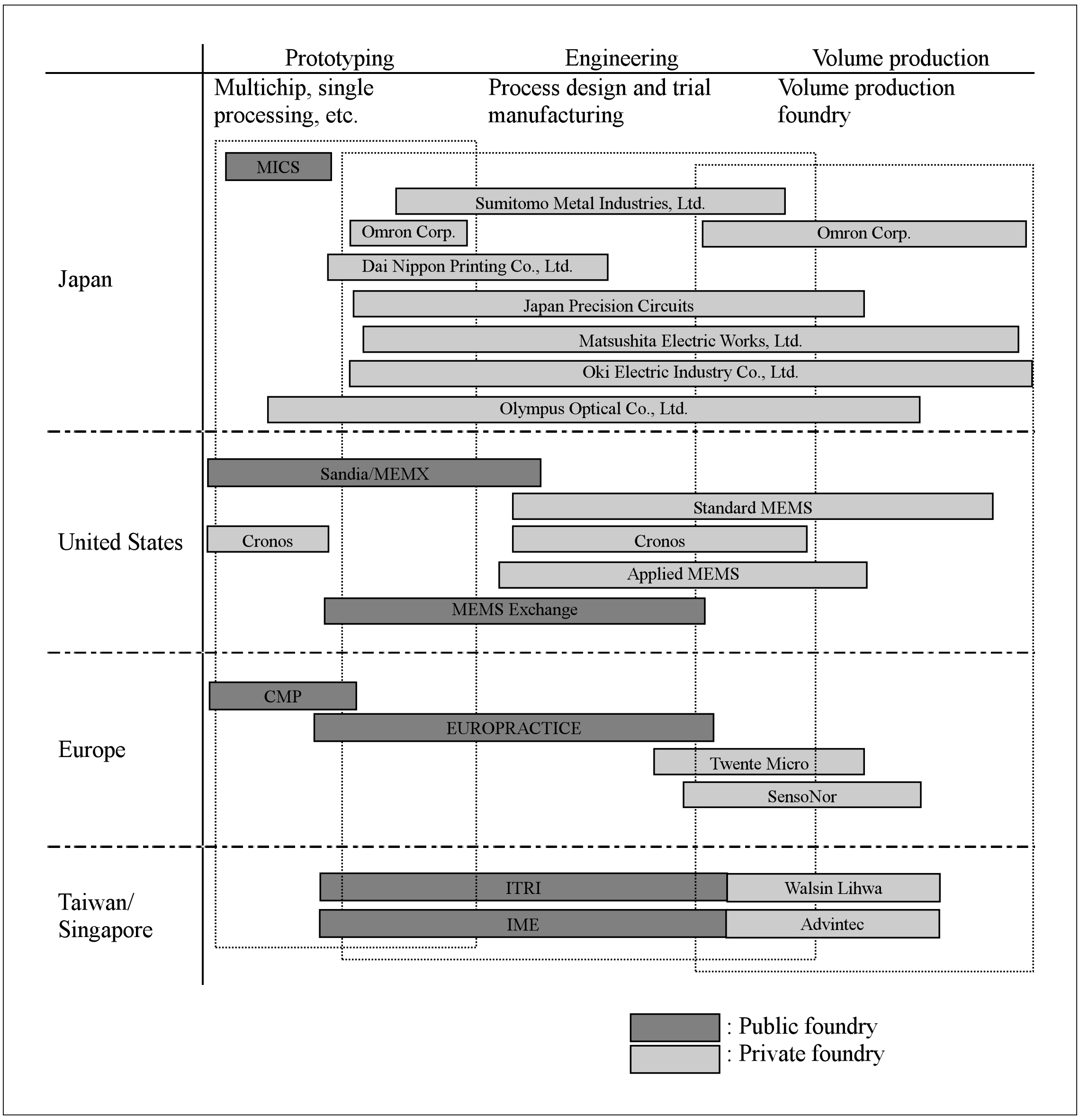
8.5 Development status of MEMS in foreign countries

8.5.1 Development status of MEMS in the United States [8,18]

In the United States, MEMS projects sponsored by DARPA (Defense Advanced Research Project Agency) were started as national projects in 1992. The outline and policy of the project leaders were announced to the public through their website. And a system has been established so that public institutions and private companies can utilize the research results.

Cronos (now JDS Uniphase), a private foundry that became independent of a nonprofit organization, undertakes trial manufacturing of MEMS, and it is now possible to place an order from overseas. They reportedly supply 15 chips in

Figure 8: MEMS foundries in the world



(According to Micromachine Center) [18]

about 11 weeks at a cost of about ¥600,000. In 1998, MEMS Exchange, a network system that connects many MEMS research bases in the United States, was established in order to contribute to the promotion of MEMS development (see Figure 8). This system is a kind of virtual fabrication on the network, and, at present, it can be used only within the United States.

In the ATP (Advanced Technology Project) sponsored by NIST (National Institute of Standards and Technology) of the Department of Commerce, which reflects more national industrial policies, research and development of sensors and displays using MEMS are also promoted.

In the United States, cooperation between universities and outside organizations is actively done, and trial manufacturing by “Spin-in” described in Section 8.4.2 is a common practice. Facilities of universities are provided not only with national funds but also with donations from private companies. It is a characteristic of the research activities at universities in the United States that mass production is taken into account in trial manufacturing, and wafers of practical size up to six inches are used even in the research facilities of some universities.

8.5.2 Development status of MEMS in Europe [18,19]

Europe started MEMS programs behind the United States. Although the scale is smaller, they have established networks corresponding to the size of Europe and open foundry systems taking after the United States (see Figure 8). The system formation was not spontaneous but purposefully carried out with French LETI (Electronics and Information Technology Laboratory), etc., at the center, so that each country of the EU functions as a member of the network. A representative MEMS network is NEXUS, and the foundry exclusive for MEMS is EUROPRACTICE; anyone can use these facilities for trial manufacturing. In EUROPRACTICE, users bear only one-third of the prototyping cost, with one-third being subsidized by local governments and the remaining one-third subsidized by the EU. They accept orders from all over the world, and some Japanese universities are using the European foundries.

8.5.3 Development status of MEMS in Asia [18,20]

As in the cases of other fields, exchanges of engineers between Western countries and Asia are growing, contributing to the rise in the technical level of Asian countries. Particularly in Taiwan and Singapore, the governments are placing great emphasis on this technology and the roles of the public sector and the private sector are clearly played. Public institutions take charge up to trial manufacturing and private foundries take charge of mass production. In Taiwan, common laboratories are provided in ITRI (Industrial Technology Research Institute of Taiwan), and private foundries such as Walsin Lihwa Corp. are implementating small-lot production of a wide variety of products after taking over the results achieved at ITRI (see Figure 8). Since MEMS manufacturing processes are difficult to standardize, it is unlikely that MEMS foundries will grow as fast as the semiconductor foundries did in the past. However, this field is being seriously considered as a remedy to avoid the hollowing-out in Taiwan, because their semiconductor foundries may be jeopardized by the uprising of China. The product field that is drawing the most attention is RF MEMS described in Section 8.4.3.

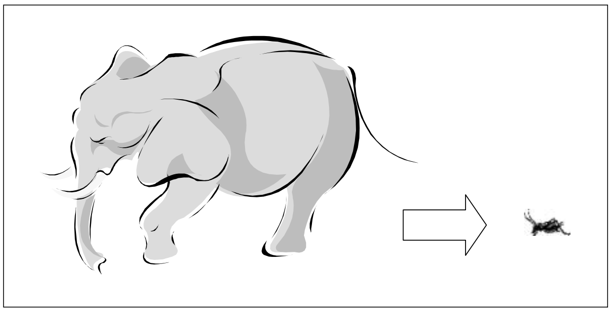
8.6 Progress from MEMS to NEMS

Many phenomena in nature are based on reactions at the nano-level, and the science intended to understand these phenomena is being rapidly developed. In the research on MEMS as well, there is a trend to mechanically or electrically reproduce such phenomena, and processing technologies at the nano-level are being investigated. Such research activities have been called NEMS (Nano Electro-Mechanical Systems) since around 2000 [21]. For example, miniature tubes provided on chips are considered to be a highly efficient reactor, because chemical reactions become more efficient with increasing surface area. The concept that intends to automatically reproduce on a chip chemical experiments that are normally carried out in chemical laboratories is called "Lab. on a Chip (Laboratory on a chip)." The pioneer in this field was the trial manufacturing of gas chromatograph in 1975 as described in Section 8.2.2.

From the viewpoint of human size, it seems that MEMS and NEMS have no great difference, but, as a matter of fact, there is a great difference comparable to that between an elephant and an insect (see Figure 9). The miniaturization from μm to nm by three orders of magnitude means that the characteristics described in Section 8.3.3 are further enhanced. Higher resonance frequency, higher mechanical response speed, lower power consumption, lower noise, and higher thermal response are expected. While many improvements are expected, it must be taken into account that the effect of surface conditions becomes greater and static electricity has stronger effects. This means that changes effected by environmental conditions cannot be neglected.

The processing accuracy required for NEMS is much severer than that required for MEMS. In the present lithography technology, it is not easy to form a line of 100 μm with a dimension error of ±1 μm; it is even less possible to obtain a dimension error of ±1 nm for 100 nm. The level of

Figure 9: There is a great difference between micro and nano, comparable to that between an elephant and an insect.



processing accuracy for NEMS is comparable to that for MEMS several decades ago [22]. Furthermore, even quantum fluctuations cannot be neglected for a line width of 10 nm or less.

For these reasons, it is not conceivable that all the research activities on MEMS should shift to NEMS. The progress in miniaturization from micro to nano is only one direction of the diversified MEMS research activities. MEMS technology essentially grows by diversification, and, in this sense, it is different from semiconductor device technology whose supreme target is miniaturization, even though the same silicon processing technology is involved. The evolution of organisms was a history of the fearless struggle for diversification, and it must be remembered that in the history of organisms any attempt to unify the form to the one considered to be the best solution at the time resulted in failure. The latest semiconductor processing technology is not always required for medical devices such as minimally invasive operation (a treatment that does not cut the body very much, such as the one in a blood vessel), biological devices such as DNA chips, and chemical devices such as micro reactors; more often than not, low costs are more important than miniaturization. For example, it has been shown that holes of about 100μm for micro reactors could be processed without using silicon processing technology [23]. Therefore, the ability to optimize the design process is required, including judgment as to whether the use of silicon processing technology is necessary.

8.7 For the promotion of research on MEMS in Japan

8.7.1 Reflection on the peculiarity of the development of MEMS in Japan

Generally speaking, it is unlikely that the quality or progress of research is affected by what the technology is called. But in the particular case of MEMS in Japan, it seems that the appellation gave a significant effect on the course of research. Even now, MEMS is often regarded as "micromachine" in Japan. As is understood from this fact, research on MEMS in Japan has been made mainly on miniature machines typically represented by micro robots. On the other hand, according to a report on the investigation of nanotechnology in the United States [24], micromachine (miniature machine) and MEMS are classified into separate fields that pursue different targets. It says that, while Japan is ahead of the United States in micromachine technology, it is far behind in MEMS technology. We must admit that such situation in the development of MEMS over the past 15 years has been caused by the difference in understanding — whether MEMS is considered as "miniature machine" or as "miniature system." In Japan, micromachine technology has progressed along with the development of robot technology in which Japan is advanced. Although Japan has made great progress in this field, commercial products are still on the way to being developed. In the past in Japan, microsensors were considered to belong to another technical field or as components used for micromachines, and they have been developed mainly by private companies as products for the parts supply business. Ironically, sensor technology has grown into one of the specialties of Japan. From now on, micromachines should be regarded as components for MEMS from a more comprehensive viewpoint.

8.7.2 Development of human resources for system engineering

As described in Section 8.3.3, capable human resources who have the ability to design a whole system are required for the research on MEMS, but it seems that Japan has a shortage of such qualified personnel. Furthermore, it has been neglected in technical education to train students in discussing what to make in the manner as described in Section 8.3.2. It has been pointed out that Japanese industries excel at "how to make" but are weak in "what to make" [13]. If one starts with "how," one cannot foster the capability to design the whole system. One of the important roles of Japanese universities and colleges in the future is to nurture the engineers of "system engineering" in its true sense.

8.7.3 Outsourcing of prototypes

MEMS products are essentially manufactured by large variety, small volume production [6]. Therefore, the mass-production-oriented concept that costs are reduced through volume production even if prototypes are expensive must be discarded, and commercialization factors must be considered from the prototyping stage. However, it is very difficult for organizations, even existing private companies, to complete the cycle from research and development through production to marketing using their own facilities.

The Venture Business Laboratory of Tohoku University and the Microsystem Technical Center of Ritsumeikan University are examples of common use facilities owned by universities in Japan. Also, there are more than 10 private foundries that accept orders for research and small-scale prototyping [25]. At present, however, most of the foundries cannot complete the desired prototyping using a single process fab, and sometimes it is impossible to complete the prototyping through multiple process fabs due to the difference in the size of silicon wafers. These problems must be solved in the future by appropriate means such as establishing networks. So, now is the time to discuss how to effectively utilize common facilities rather than constructing new clean rooms for MEMS.

In the past, Japanese universities were unwilling to carry out "fab-less" research, that is, without having their own facilities to make the prototypes. However, it is unrealistic for universities to have on their own all the silicon processing facilities required for providing prototypes. It is not always economical even for private companies. If the research on MEMS is understood as the "creation of a new system," it is more efficient for studying "system engineering," from the viewpoint of time and economy, to eliminate the intermediate prototyping stage. For education in MEMS, more time should be spent on the verification and analysis of finished products. To operate trial manufacturing fabs that require diversity, the researchers must prepare a considerable amount of expense and labor as well as a certain number of exclusive operators to keep them. It is necessary to avoid increasing the number of inefficient facilities neglecting these disadvantages.

In March 2002, the Mechanical Social Systems Foundation published a report compiled by the Micromachine Center called the "Report on the Investigation of the Foundry Network System Concept for Micro/Nanotechnologies, Fiscal Year 2001" [18]. This report points out that there is a mismatch between the expected initial market size of MEMS and enormous investment required for the processing facilities. It also advises that in order to clear entry barriers, network systems (FNS) should be established so that assets and technologies, which are now being developed randomly and separately, are integrated for the best efficiency. In the concept of FNS, research activities at universities and public institutions and developments by private companies are integrated into one system. When establishing a network, it is important to make its size appropriate to the market size and funding ability, and European systems should be considered as models to follow.

8.7.4 Promotion of the venture aspect of MEMS research

Regarding MEMS research activities, it is worth noting that the orientation of research at universities and that of the industry are in the same direction, showing little discrepancy between the two. This means that MEMS research is an appropriate theme for the cooperative work between industry and academia. It also should be noted that MEMS is suitable for commercialization by small-size companies and venture businesses.

Particularly, medical- and biology-related technologies represent fields where venture businesses are created most, with about 1,300 companies in the United States and more than 200 companies in Japan having been established up to now [26]. Included among these venture businesses are companies created by MEMS technology. For example, Protein Wave was established in 2000 based on μ-TAS (μ-Total Analysis), a technology for the crystallization of protein indispensable in the research of genome (gene information) [27]. They plan to commercialize silicon chips provided with grooves or dents, in which protein solutions to be crystallized are poured. They also intend to develop new medicines by themselves. A road to fund procurement has been opened in this field. For example, a venture development association has established [28] and a business plan competitions have been held [29].

8.7.5 Services available in Japan

If funds are sufficient, there is no restriction for using universities and private foundries for the research on MEMS. As a matter of fact, however, universities without facilities and researchers who intend to create venture businesses are suffering from financial barriers. For these people, one solution may be to utilize the facilities of other universities and public institutions.

The following are examples of services available to anyone. As for universities, the two mentioned in Section 8.7.3 have the most experience. The Institute of Electrical Engineers of Japan offers a service called MICS (Micromachine Integrated Chip Service), which provides micromachine integrated chips [12]. In this service, multiple prototypes are shared on one mask in order to save the costs of trial manufacturing. But it must be said that the available technologies are limited. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) has established a technical support system called the Nanotechnology Support Project, and designated 14 organizations that anyone can use at no charge. In this project, MEMS prototyping technology is included [30]. Other than universities, efforts by public institutions for shared research are not yet active [18], however, one example of services provided by local governments is the Technical Support Center for Micro Device Development of the Technology Research Institute of Osaka Prefecture [31].

Some universities and private companies already have experience in ordering prototypes of MEMS from foundries in Europe and Taiwan, and international cooperation has started in order to cover the lack of domestic prototyping facilities. However, if Japan loses the capability to develop MEMS by itself, the hollowing-out of industry would accelerate because the MEMS industry also requires an integrated system from development to manufacturing.

8.8 Conclusion

The research and development of MEMS is an activity that creates new systems by integrating microelectronics, nanoscience and other technologies into micromachine and sensor technologies that have been the specialty of Japan. It requires system engineering education that discusses "what" to make rather than "how" to do, and it is very important to foster human resources to handle the overall design including all of conceptualization, design, and prototyping. Also, for Japanese universities and private foundries for MEMS, which are now being arranged to function effectively for the vitalization of industry including venture businesses, it is necessary to make organic systematization taking after Europe.

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9

The Status of Japan's Participation in Science and Technology Contests

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9.1 Introduction

A variety of science and technology contests are currently held in Japan. International science and technical contests began in the 1950s, and have developed by adding new fields such as Informatics. In Japan, mathematical, scientific research, technology, and other competitions are held, some of which include participants from overseas. Their existence, however, is not widely known.

In this article, therefore, we will present an overview of science and technology contests held on an international scale and describe Japanese participation in them. We will report on the following contests.

- **Contests related to science and technology education**
  International Science Olympiad (mathematics, physics, chemistry, informatics, biology, astronomy), International Science and Engineering Fair (ISEF)
- **Contests related to technology**
  ACM International Collegiate Programming Contest, Supercomputer Programming Contest, NHK Robocon (robot contest), RoboCup
- **Contests relating to skills**
  World Skills Competition

9.2 Overview of contests related to science and technology education.

9.2.1 International Science Olympiad

Targeting high school students (formally, students in secondary education), six Science Olympiads are held every year (Table 1). Each originated in Eastern Europe, and each has seen participation expand from the former communist bloc to include the West. With the exception of the Astronomy Olympiad, each Science Olympiad rotates among the participating countries, and each country is obligated to host the competition in the future. There is no unified governing body to oversee the different Science Olympiads.

The purposes of the competitions are to encourage learning by interested and talented young people, to foster originality and creativity, and to build international friendship through interaction among the participants. Overall, an Olympiad takes about 10 days, and in addition to the actual tests includes visits to relevant facilities, sightseeing, and social events.

To carry out the Olympiads, regulations and syllabi are determined and operating organizations are set. In the case of the Mathematical Olympiad, for example, a 10-member preparation committee including host country (previous, current, next) representatives is permanently in place. The committee provides information to participating countries, makes contact with and advises scheduled host countries, and exchanges information with relevant organizations such as UNESCO and the Science Olympiads. During the competition, the jury including the leaders of country delegations is formed and becomes the final decision making body. The selection of contest problems, the evaluation of answers, the determination of prizewinners, the revision of regulations, and the selection of future host countries are done there.

Following are overviews of the mathematics, physics, chemistry, and informatics Olympiads large enough to attract major international

Table 1: Overview of the International Science Olympiads for high school students

	Mathematical Olympiad	Physics Olympiad	Chemistry Olympiad	Olympiad in Informatics	Biology Olympiad	Astronomy Olympiad
Year/place 1st held	1959 Romania	1967 Poland	1968 Czechoslovakia	1989 Bulgaria	1990 Czechoslovakia	1996 Russia
Major participants and 1st year participating	1959: USSR 1967: France 1967: UK 1974: USA 1977: W.Germany 1985: China	1968: USSR 1972: France (non-participant since 1985) 1974: W.Germany 1984: UK 1986: USA 1987: China	1970: USSR 1975: W. Germany 1976: France 1983: UK 1984: USA 1987: China	1989: W. Germany, USSR, China 1990: UK 1992: USA 1996: France	1990: USSR 1990: Germany 1993: China 1998: UK	1996: Russia 1998: India 1999: Sweden 2001: Italy, S. Korea
Participating countries	84 (2002)	66 (2002)	57 (2002)	72 (2001)	40 (2002)	8 countries, 1 region (Moscow) (2001)
Team composition	6 or fewer contestants, 2 leaders	5 or fewer contestants, 2 leaders	4 or fewer contestants, 2 leaders	4 or fewer contestants, 2 leaders	4 or fewer contestants, 2 leaders	5 or fewer contestants, former prize winners, 2 leaders
Test problems and time to complete	6 problems (2 days, 9 hours total)	3 theoretical problems (1 day, 5 hrs., 30 points) 1-2 practical problems (1 day, 5 hrs, 20 points)	1 theoretical problem (1 day, 4-5 hrs., 60 points) 1 practical problem (1 day, 4-5 hrs. 40 points)	6 problems (2 days, 10 hrs. total)	1 theoretical problem (1 day, 4-6 hrs.) 1 practical problem (1 day, 4-6 hrs.) Weighted 1:1	4-6 theoretical problems (4 hrs., 60 points) 1-2 practical problems (3 hrs., 20 points) 1-2 observation problems (20 points)
Prizes	Gold Medal (top 1/12 of participants) Silver Medal (top 2/12) Bronze Medal (top 3/12) Honorable Mention (at least 1 problem correct)	Gold Medal (at least 90% of the average of the top 3 scores) Silver Medal (at least 78%) Bronze Medal (at least 65%) Honorable Mention (at least 50%)	Gold Medal (top 10% of participants) Silver Medal (top 20%) Bronze Medal (top 30%) Honorable Mention (at least 1 problem correct)	Gold Medal (top 1/12 of participants) Silver Medal (top 2/12) Bronze Medal (top 3/12)	Gold Medal (top 10% of participants) Silver Medal (top 20%) Bronze Medal (top 30%)	—
Recent results	1 China, 2 Russia, 3 USA, 4 Bulgaria, 5 Vietnam, 6 S. Korea, 7 Taiwan, 8 Romania, 9 India, 10 Germany (2002)	1 China, 2 Iran, 3 S. Korea, 4 Russia, 5 Hungary, 6 Indonesia, 7 India, 8 Taiwan, 9 Romania, 10 Georgia (USA did not participate in 2002)	1 China, 2 Thailand, 3 Taiwan, 4 Ukraine, 5 Austria, 6 S. Korea, 7 USA, 8 Germany, 9 Poland, 10 Iran (2002)	1 Slovakia, 2 USA, 3 Singapore, 4 Finland, 5 S. Korea, 6 Romania 7 Poland, 8 Bulgaria, 9 Vietnam, 10 Germany (2001)	1 China, 2 S. Korea, 3 Taiwan, 4 Singapore, 5 Thailand (2002)	1 Russia, 2 India (2002)
Japanese participation	Since 1990 (scheduled to host 2003 competition)	None (Participation being considered by relevant academic organizations) (Observer at 2001 Asian competition)	Scheduled to begin in 2003 (Observer at 1989 and 2002 competitions)	1994-1996	None (Observer at 1995 competition)	None

Note: The Science Olympiads are individual competitions; no country standings are announced. The standings above are calculated as follows: total points in the Mathematical Olympiad, total points for prize winners in the Physics Olympiad, aggregate placement in the Chemistry Olympiad, and number of prize winners in the Astronomy Olympiad.

Sources: relevant websites [1]

Figure 1: Sample problems from the Mathematical Olympiad (42nd Olympiad, July 2001, USA)

Day 1, July 8 (Test time 4 hours 30 minutes; each problem 7 points)

1. Let ABC be an acute-angled triangle with circumcenter O. Let P on BC be the foot of the altitude from A. Suppose $\angle BCA \geq \angle ABC + 30^\circ$ prove that $\angle CAB + \angle COP < 90^\circ$.

2. Prove that
$$\frac{a}{\sqrt{a^2+8bc}} + \frac{b}{\sqrt{b^2+8ca}} + \frac{c}{\sqrt{c^2+8ab}} \geq 1.$$
for all positive real numbers a, b and c.

3. 21 girls and 21 boys took part in a mathematics contest.
• Each contestant solved at most six problems.
• For each girl and each boy, at least one problem was solved by both of them.
Prove that there was one problem that was solved by at least three girls and at least three boys.

Source: Mathematical Olympiad Foundation of Japan website (http://village.infoweb.ne.jp/~fvgm9250/)

participation.

(1) IMO:
International Mathematical Olympiad

— Overview

The first International Mathematical Olympiad was held in 1959, with Hungary, Bulgaria, Poland, former Czechoslovakia, former E. Germany, and the former Soviet Union participating at the invitation of Romania. Western countries steadily joined thereafter, including Finland in 1965, France, the United Kingdom, Italy, and Sweden in 1967, the United States in 1974, and West Germany in 1977. Japan first participated at the 31st Mathematical Olympiad, held in China in 1990. Four hundred eighty-one people from 84 countries participated in the 43rd Olympiad in 2002. Japan is scheduled to host the 44th Olympiad in 2003.

The problems focus mainly on geometry, mathematical theory, and discrete mathematics, which are not widely taught in Japanese high schools. Calculus and linear algebra are not included. (Figure 1)

— Japanese participation and results

Japan selects its competitors through the annual Japan Mathematical Olympiad held by the Mathematical Olympiad Foundation of Japan. Of the approximately 1,500 participants in preliminaries held all over Japan, about 100 pass and move on to the finals. In the finals, approximately 20 high scorers are chosen for a weeklong training camp at which the 6 Japan representatives are chosen.

Table 2: Recent results

	41st Olympiad (2000)	42nd Olympiad (2001)	43rd Olympiad (2002)
Participating countries	82	83	84
1st	China	China	China
2nd	Russia	Russia, USA	Russia
3rd	USA	—	USA
4th	S. Korea	Bulgaria, S. Korea	Bulgaria
5th	Bulgaria, Vietnam	—	Vietnam
6th	—	Kazakhstan	S. Korea
7th	Belarus	India	Taiwan
8th	Taiwan	Ukraine	Romania
9th	Hungary	Taiwan	India
10th	Iran	Vietnam	Germany
Japan	15th	13th	16th

Source: Mathematical Olympiad Foundation of Japan website (http://village.infoweb.ne.jp/~fvgm9250/)

Table 3: Placement trends since 1990

	China	Russia (former Soviet Union)	USA	S. Korea	Germany	Japan	France	UK
1990	1	2	3	32	7 (East) 12 (West)	20	5	10
1991	2	1	5	17	4	12	13	18
1992	1	6	2	18	7	8	10	5
1993	1	4	7	16	2	20	17	14
1994	2	3	1	14	12	10	19	7
1995	1	3	11	7	15	9	30	10
1996	6	4	2	8	10	11	36	5
1997	1	4	4	11	13	12	32	16
1998	(DNP)	6	3	12	16	14	26	17
1999	1	1	10	7	17	13	33	20
2000	1	2	3	4	20	15	48	22
2001	1	2	2	4	14	13	28	31
2002	1	2	3	6	10	16	19	27

Source: Mathematical Olympiad Foundation of Japan website (http://village.infoweb.ne.jp/~fvgm9250/) and materials

The Olympiad is an individual competition, but if we add the points of participants to get country placements, Japan finishes in the upper half of the second 10 (see Table 2). Special training for participants and potential competitors takes place in every country. In most places, like Japan, that training is one or two weeks long, but some countries are make more intense efforts. In the former Soviet Union, for example, organized selection and gifted education were carried out, while in China training could last for several months. South Korea offered nationwide support when the Olympiad was held there in 2000.

Looking at results since 1990, Japan has been holding steady in the second 10. China and Russia regularly finish at the top, while the United States has relatively large swings but usually finishes among the leaders. Germany, France, and the United Kingdom were on a downward trend, but have regained their positions. The longtime participants from Eastern Europe and the former Soviet Union also appear among the leaders. In Asia, South Korea has shown remarkable progress, while Iran and Vietnam have also taken their places among the leaders (see Table 2 and 3).

(2) IPhO: International Physics Olympiad

The first International Physics Olympiad was held in Poland in 1967 with five Eastern European nations participating. Sixty-six countries took part in the 33rd Olympiad in 2002. An Asian Physics Olympiad has been held since 2000.

In Japan, education committees of the Physical Society of Japan and the Japan Society of Applied Physics have been considering the International Physics Olympiad since 1990.[2] At the 57th annual meeting of the Physical Society of Japan this past spring, the Physics Education Society of Japan and the physics education subcommittee of the Japan Society for Applied Physics held a joint symposium where they discussed issues such as the value of participation, the required conditions to do so, and gaps between the Olympiad problems and Japanese curricula.

(3) IChO: International Chemistry Olympiad

The first International Chemistry Olympiad was held in 1968 at the suggestion of former Czechoslovakia. Hungary and Poland were the other participating countries. In 2002, 57 countries took part in the 34th Olympiad.

In Japan, the Chemical Society of Japan and the Chemical Education Society of Japan studied the Olympiad and sent observers to the 1989 contest. They did not attempt to participate due to the difficulties of securing funds and competition facilities and the difference in content between the Olympiad and Japanese high school curricula.

Since 1998, however, the Chemical Society of Japan, its Chemistry Education Council, the "Yume Kagaku 21 Committee" (including Chemical Society of Japan, Society of Chemical Engineers, Japan, Association for the Progress of New Chemistry, Japan Chemical Industry Association) have been holding the High School Chemistry Grand Prix, which is patterned after the Chemistry Olympiad, so a domestic competition system is now in place. Competitors selected at this year's contest will be sent to participate in the 2003 Olympiad in Greece.[3]

(4) IOI:
International Olympiad in Informatics

The first International Olympiad in Informatics was held in 1989, with 13 countries including Bulgaria, China, East and West Germany, and the Soviet Union participating. Seventy-two countries took part in the 13th Olympiad in 2001.

Japan sent delegations to the International Olympiad in Informatics from 1994 through 1996, treating it as a part of the International Mathematical Olympiad. Domestic competition and participation in the international competition were enabled by financial support from the Mathematical Olympiad Foundation of Japan and the volunteer work of university professors. Since 1997, however, no teams have been sent due to a lack of a dedicated source of funds and less than expected growth in domestic participation. Since the field is not designated as a subject in Japanese schools (the emphasis is different from the informatics that will be introduced in high schools next year), and because the difficult economic conditions in Japan make it unlikely that funding can be found, resumed participation is not being considered.

9.2.2 ISEF: International Science and Engineering Fair[4]

— Overview

The International Science and Engineering Fair is operated by Science Service, a non-profit organization in the United States. This science and engineering competition for high school students has been held annually throughout the USA since 1950. Alumnae/i of the competition include five Nobel laureates and two winners of the Fields Medal, as well as many other distinguished scientists. The quality of the exhibits is so high that about 15 percent of them have U.S. patents applied for. Since Intel became the event's primary sponsor in 1997, new prizes have been added and international participation has increased.

Participants are selected through cooperating competitions in each foreign country and U.S. state. No more than two individuals and one group are accepted from each contest. Participants display their projects in separate booths, and are judged by 700 to 900 judges on originality, scientific thought, and technical completeness. Approximately 1,200 people (80 percent of them from the USA) from each U.S. state and 40 foreign countries including the UK, Germany, Canada, Russia, Australia, China, Taiwan, and South Korea took part in the 2002 Fair.

The 15 sectors of the Fair include 14 fields (behavioral/social science, biochemistry, botany, chemistry, computer science, earth/space science, engineering, environmental science, gerontology, mathematics, medicine/health care, microbiology, physics, zoology) plus team projects.

First to fourth place winners in each sector receive awards and prize money. (More than one winner receives each kind of prize.) Three participants are selected from among all prizewinners to receive the Intel Young Scientist award, which includes a trip to the Nobel Prize award ceremony and a $50,000 scholarship. Other companies and organizations sponsor their own prizes as well.

The Fair lasts one week, and in addition to the judging of the projects by specialists, it includes lectures by invited Nobel laureates (open to the public), corporate exhibits, a dance, and sightseeing. An enjoyable atmosphere is created for the awards ceremony, with teams from each country wearing uniforms, waving flags, and cheering. The event is so popular that even the competition to host it can become intense.

— Japanese participation and results

Since 1958, high school winners of the Japan Students Science Award (sponsored by the Yomiuri Shimbun Co.) have gone on to ISEF. Created in 1957, the Japan Students Science Award is an open scientific research competition for junior high and high school students. Its fields are physics, chemistry, biology, earth science, and interdisciplinary. Because there are no other Japanese competitions with links to ISEF, the number of participants from Japan remains very small.

At the 52nd ISEF in 2001, among Japan's two individuals and one team participating, the team project won a fourth-place prize. Two Japanese individuals participated in the 53rd ISEF in 2002, taking home a third place in botany and a fourth place in physics.

9.3 Contests related to technology

9.3.1 ACM/ICPC: ACM International Collegiate Programming Contest

— Overview

Sponsored by the Association for Computing Machinery (ACM) of the USA, this is the world's oldest and largest programming competition for college students. Its is to provide college students with opportunities to improve their problem solving abilities and computer skills.

Based on a contest first held in 1970, in 1977 the contest became a multi-round competition with finals. The contest network has expanded to universities around the world since the 1980s. Now teams battle in regional competitions in six regions, and the best move on to the world contest. Since IBM became its sponsor in 1997, the contest has grown roughly three times as large. Today 17,000 individuals on over 3,000 teams from more than 1,300 colleges and universities in 67 countries compete in the contest. At the 26th world finals in 2002, 64 teams (2 from Africa and the Middle East, 15 from Europe, 5 from Latin America, 25 from North America, 2 from Oceania, 15 from Asia) selected through 29 regional contests vied for the championship.

At the world finals, three-person teams work to solve about eight problems. Time is limited to five hours. Teams finishing in 1st through 3rd places win gold medals, those in 4th through 6th win silver, and those in 7th through 10th win bronze. Scholarships are awarded along with the medals.

— Japanese participation and results

Japan has participated in the world finals since 1998, and in the Asian regionals since 1997.

To move on to the world finals, a Japanese team must give an outstanding performance in the Asian regionals, which include Japan, South Korea, China, Iran, and so on. In the 2001 Asian regionals, eight regional preliminaries were held. (Each team may compete in two regional preliminaries.) In addition to the first-place teams in each regional preliminary, performance, hosting, and female participation were considered in choosing the remainder of the 15 teams that went on to the world finals in 2002.

Results at the world finals since Japan began competing in 1998 are shown in Table 4. Over those five years, the United States has placed in the top 10, 12 times, Russia 8 times, Canada 8 times, and China 7 times.

9.3.2 Supercomputer Programming Contest [5]

Since 1995, the Tokyo Institute of Technology's Global Scientific Information and Computing Center has held a national programming contest for high school students with the goal of having supercomputers play a positive role in society. The contest requires problem solving skills as well as programming techniques.

Preliminaries are judged based on documents including the program submitted, the results of running the program, and a report with an overview of the program's algorithms. Ten of the 30 to 40 three-person teams competing move on to the finals. There they spend four days tackling university-level problems under the guidance of instructors. Not merely a contest, the event is notable for including lectures and other educational features as well as promoting interaction among the participants.

Winning teams through 1998 attended the SuperComputing conference in the USA. Since 1999, workstations have been donated. Top finishers this year will have the opportunity to present their results at a joint national conference of the Information Processing Society of Japan and the Institute of Electronics, Information and Communication Engineers.

Table 4: ACM/ICPC Results since 1998

	1998	1999	2000	2001	2002
1st	Charles U.-Prague (Czech Rep.)	U. of Waterloo (Canada)	St. Petersburg U. (Russia)	St. Petersburg U. (Russia)	Shanghai Jiao Tong U. (China)
2nd	St. Petersburg U. (Russia)	Albert-Ludwigs U. (Germany)	U. of Melbourne (Australia) U. of Waterloo (Canada)	Virginia Tech. (USA)	Massachusetts Inst. of Technology (USA)
3rd	U. of Waterloo (Canada)	St. Petersburg Inst. of Fine Mechanics and Optics (Russia)	Albert Einstein U. Ulm (Germany)	St. Petersburg Inst. of Fine Mechanics and Optics (Russia)	U. of Waterloo (Canada)
4th	U. of Umea-Sweden (Sweden)	Bucharest U. (Romania)	St. Petersburg Inst. of Fine Mechanics and Optics (Russia) Tsinghua U. (China)	U. of Waterloo (Canada)	Tsinghua U. (China)
5th	Massachusetts Inst. of Technology (USA)	Duke U. (USA)	—	Albert Einstein U. Ulm (Germany)	Stanford U. (USA)
6th	U. of Melbourne (Australia)	California Polytechnic State U. (USA)	—	Warsaw U. (Poland)	Saratov State U. (Russia)
7th	Tsing Hua U.-Beijing (China)	U. of California at Berkeley (USA)	Kyoto U. (Japan) Shanghai Jiao Tong U. (China)	Massachusetts Inst. of Technology (USA)	Fudan U. (China)
8th	U. of Alberta (Canada)	Harvard U. (USA)	U. of Alberta (Canada) The Chinese U. of Hong Kong (China)	Seoul National U. (S. Korea)	Duke U. (USA)
9th	Warsaw U. (Poland)	St. Petersburg State U. (Russia)	California Inst. of Technology (USA)	Sharif U. of Technology (Iran)	Moscow State U. (Russia)
10th	Polytechnic U. Bucharest (Romania)	National Taiwan U. (Taiwan)	Charles U. Prague (Czech Rep.)	Harvard U. (USA)	U. of Buenos Aires (Argentina)
Japan	30+: Kyoto U.	18th: Kyoto U.	7th: Kyoto U.	14th: Kyoto U.	18th: U. of Tokyo

Source: ACM/ICPC website (http://icpc.baylor.edu/)

9.3.3 NHK Robocon (robot contest)

Based on a proposal by Masahiro Mori, emeritus professor at Tokyo Institute of Technology, to give young people a taste of the importance of creativity and the wonder of making, technical colleague Robocon was established in 1988 and all 62 schools have been participating in the regional preliminaries since the third Robocon,. IDC Robocon (mixed teams of university students from various participating countries compete) was established in 1990, and University Robocon was established in 1991. In each contest, contestants build robots based on a theme and test their success by competing against one another. With the contest broadcast on national television, it is very well-known and has become a major goal for many students.

Foreign universities have participated since the third University Robocon, and have won the last three in a row (see Table 5). This year the Asia-Pacific Broadcasting Union (ABU) established the ABU Asia-Pacific Robot Contest, and University Robocon also became the contest to select the Japanese team. At the 2002 ABU Robocon held at the end of August, 21 teams from 20 countries and territories (host Japan had two teams) participated.

Table 5: NHK Robocon Recent results (through 2001)

Year	6th (1997)	7th (1998)	8th (1999)	9th (2000)	10th (2001)
Participating schools	Japanese: 19 Foreign: 3 (Indonesia, Thailand, China)	Japanese: 15 Foreign: 5 (China, Singapore, Thailand, Australia)	Japanese: 12 Foreign: 8 (Indonesia, China, Thailand, Philippines, France, Australia)	Japanese: 13 Foreign: 7 (Indonesia, China, Thailand, France, Australia)	Japanese: 14 Foreign: 6 (Indonesia, China, Thailand, France, France,
Winner	Nagaoka University of Technology	Toyohashi University of Technology	Bangkok University (Thailand)	King Mongkut's University of Technology Thonbu (Thailand)	Politeknik Elektronika Negeri Surabaya (Indonesia)
2nd place	Nagasaki Institute of Applied Science	King Mongkut's University of Technology Thonbu (Thailand)	Nagaoka University of Technology	Nagaoka University of Technology	Kyushu University

Source: NHK University Robocon website (http://www.nep21.co.jp/robocon/jp/daigaku/)

Table 6: RoboCup 2002 results by league

League	1st	2nd	3rd
Soccer (simulation)	TsinghuAeolus (China, Tsinghua University)	Everest (China, Beijing Institute of Technology)	Brainstormers (Germany, Universitaet Dortmund)
Soccer (small robots)	Big Red (USA, Cornell University)	FU Fighters (Germany, Freie Universitaet Berlin) Lucky Star (Singapore, Ngee Ann University)	—
Soccer (medium robots)	EIGEN (Keio University)	WinKIT Kanazawa Institute of Technology	Osaka University Trackies (Osaka University)
Soccer (4-legged robots)	CMPack'02 (USA, Carnegie Mellon University)	rUNSWift (Australia, University of New South Wales)	Nubots (Australia, University of Newcastle)
Soccer (2-legged robots)	NAGARA (Gifu Prefecture Industrial Association)	—	—
Rescue (simulation)	Arian 2002 (Iran, Shari University of Technology (SUT))	YowAI 2002 (University of Electro-Communications)	NITRescue02 (Nagoya Institute of Technology)
Rescue (Robots)	KAVOSH (Iran, Javan Robotics Club)	MARR (Tokyo Institute of Technology)	—
Junior (middle/high school 1-on-1 soccer)	Team finland (Finland)	Slovakia (Slovakia)	SG-2 [George] (Thailand)
Junior (middle/high school 2-on-2 soccer)	E-strikers (Australia)	Pilatoren (Germany)	snowwhite (Germany)
Junior (elementary school 2-on-2 soccer)	winning 3 (Japan)	Tokai 1 (Japan)	Samurai-damashii (Japan)
Junior (dance)	beautiful sky (Japan)	Victory (Japan)	SAKURA (Japan)

Source: RoboCup 2002 website (http://www.robocup2002.org.japanese/index.html)

9.3.4 RoboCup: The Robot World Cup Initiative

RoboCup is an international research project to promote research in fields such as robotics and artificial intelligence. Proposed primarily by Japanese researchers, it is based on this vision: "By mid-21st century, develop a team of fully autonomous humanoid robot soccer players shall win the soccer game, comply with the official rule of the FIFA, against the winner of the most recent World Cup." Competition among autonomous robots at RoboCup international competitions is seen as one method to promote research. Following the competitions, conferences are held to present the research of participants, and technical data are made public. The RoboCup International Committee is the international governing organization, while the Japan RoboCup Committee is the organization in Japan.

After two years of implementation-oriented research beginning in 1993, the concept was announced in 1995, and the first competitions and conference were held in 1997 in Nagoya. Following RoboCups in Paris, Stockholm, Melbourne, and Seattle, the sixth RoboCup was held jointly in 2002 in Pusan, Korea, and Fukuoka, Japan. The Japan Open has also been held since 1998.

In addition to RoboCupSoccer, current fields include RoboCupRescue for the application of robots to large-scale disaster rescue (since 2001), and the RoboCupSoccer Humanoid League (beginning this year) for autonomous bipedal robots. RoboCupJunior (since 2000) is for elementary, middle, and high school students, and offers local robot-building classes in addition to the competition. The categories are as follows.

— Soccer
  Simulation, small size, middle size, four-legged, humanoid.
— Rescue
  Simulation, robot.
— Junior
  Soccer, rescue, dance (varies by age).

At the 2002 Fukuoka-Pusan RoboCup, 1,004 people on 188 teams from 29 countries (including 234 people on 58 teams from 12 countries in the Junior category) participated. Results by league are shown in Table 6 below.

9.4 Overview of contests related to skills

9.4.1 World Skills Competition

— Overview

Operated by the International Vocational Training Organization, the World Skills Competition is held in odd-numbered years. The international headquarters is in Switzerland, while the International Organizing Committee office is in Spain. The goals of the competition are the promotion of vocational training in participating countries and international exchange and friendship among young trades people.

The competition began in 1950 as a contest between 12 competitors from Spain and 12 from Portugal. In 1966, the Skills Olympics Organizing Committee was formed by representatives from participating countries, and the competitions are carried out under rules set by that committee. Member countries have steadily increased, and currently include 38 countries and territories. Six hundred and sixteen people from 35 countries took part in the 36th World Skills Competition. Participants must be age 22 or younger during the year of the competition.

The competition lasts 22 hours over four days. There are three categories of trades in the competition, official, demonstration, and other. Official trades are limited to 40, so a new trade can be entered only by replacing an existing one. Each participating country can enter one competitor per trade (two for landscape gardening and mechatronics). The following 39 trades were included in the 2001 competition.

Fitting, press tool making, instrument making, mechatronics, engineering drafting/CAD, turning/CNC, milling/CNC, construction steel work, information technology, welding, pattern making, autobody repair, sheet metal work, commercial wiring, industrial electronics, industrial wiring, plumbing, automobile technology, car painting, wall and floor tiling, bricklaying, stonemasonry, painting and decorating, plastering, cabinetmaking, joinery, carpentry, jewelry, floristry, ladies' hairdressing, men's hairdressing, ladies' dressmaking, cooking, waiting, refrigeration, IT PC and network support, landscape gardening, graphic design, confectioner.

Gold, silver, and bronze medals are awarded to the competitors who finish first, second, and third in their respective trades. In addition, competitors who score more than 500 points receive a Diploma of Excellence. The highest scorer in the entire competition receives the Albert-Vidal award, and the highest scorer from each country receives a "Best of the nation" medal. The female competitor with the highest score in a male-dominated trade also receives a special award. ("Male-dominated trades" are determined by the Technical Committee before the competition).

— Japanese participation and results

Japan has been participating since the 11th competition in 1962. The winners of Japan's national championships in the year prior to the World Competition go on to compete there. Japan hosted the 19th (1970) and 28th (1985) competitions, and will host for the third time in 2007.

Thirty-three Japanese competed in 31 categories at the 36th competition in 2001. They won 4 gold medals (in fitting, instrument making, milling/CNC, and industrial wiring), 2 silver (in press tool making and sheet metal work), and 4 bronze (in pattern making, autobody repair, industrial electronics, and ladies' dressmaking), for a total of 10 medals in all. Japan was third in gold medals and fourth in total medals (see Table 7).

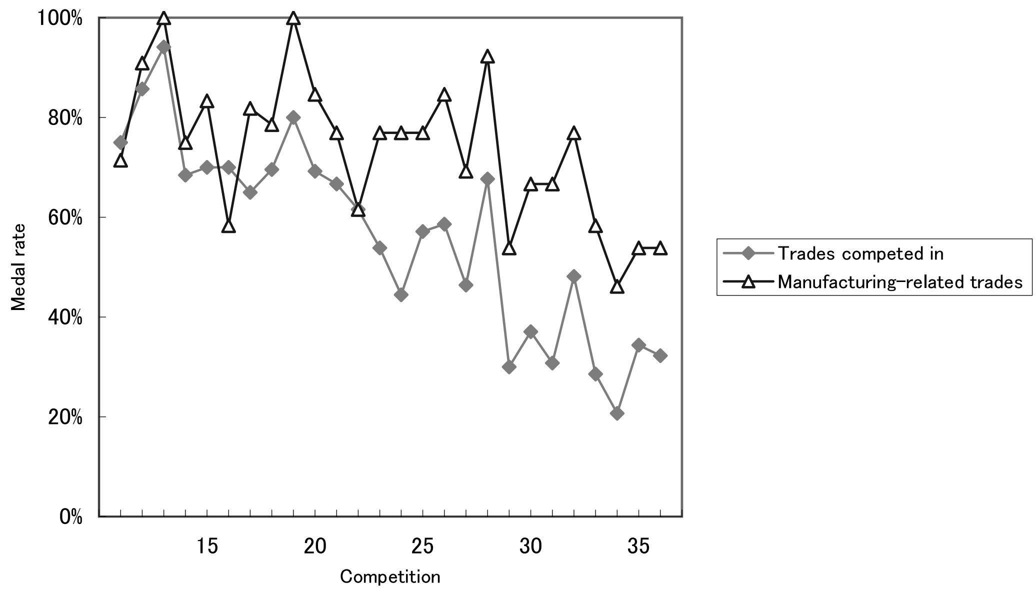
Japan consistently finished first or second

Table 7: Recent competition results (in order of gold medals received; numbers in parentheses are gold/total medals)

	31st competition (1991)	32nd (1993)	33rd (1995)	34th (1997)	35th (1999)	36th (2001)
Location	Netherlands	Taiwan	France	Switzerland	Canada	South Korea
1st	South Korea (13/18)	Taiwan (18/32)	South Korea (10/18)	South Korea (10/17)	South Korea (7/16) Taiwan (7/16)	South Korea (20/32)
2nd	Taiwan (8/20)	South Korea (12/20)	Taiwan (6/17)	Taiwan (8/17) Switzerland (8/19)	—	Germany (5/10)
3rd	Austria (6/10)	Germany (3/8)	Japan (4/8) Germany (4/7) Switzerland (4/6)	—	Japan (6/11)	Japan (4/10) Austria (4/7)
4th	Japan (4/8) Switzerland (4/8)	Japan (2/13) France (2/10) Ireland (2/4) Switzerland (2/3)	—	France (7/10)	Switzerland (5/15)	—
5th	—	—	—	Germany (4/10) Austria (4/9)	Austria (3/10) Australia (3/4) France (3/10)	Taiwan (3/16) Switzerland (3/11) France (3/7) Australia (3/4)
Other countries with at least 5 medals	Germany (3/12) Netherlands (3/9) France (3/7) England (0/6) Australia (0/5)	Austria (1/9) England (0/9) Netherlands (0/7) Australia (0/5)	Australia (3/10) France (1/8) England (3/6)	Australia (3/5) Netherlands (0/5)	Germany (2/9) Ireland (2/7)	Singapore (2/5)
Japan	4th	4th	3rd	8th (2/6)	3rd	3rd

Source: Japan Vocational Ability Development website (http://www.javada.or.jp/jigyou/gno/kokusai/) and materials.

Figure 2: Japan's medal rate



Note: Manufacturing-related trades are considered to be the following. Fitting, press toll making, instrument making, mechatronics, engineering drafting/CAD (separate trades in 1993), turning/CNC, milling/CNC, construction steel work, welding (2 trades, gas welding and electrical welding, through 1985), pattern making, autobody repair (sheet metal embossing from 1963 through 1991, industrial sheet metal in 1962), sheet metal work, commercial wiring, iron casting (1962-1970), mechanical forging (1962-1964).

Source: Calculated from Japan Vocational Ability Development Association materials.

through about the 20th competition (1971). Since then, South Korea has taken over the top position, and Japan has finished second, third, or lower. Japan's eighth place finish in 1997 at the 34th competition was its worst ever, but it has bounced back since then. South Korea and Taiwan have distanced themselves form the other competitors in terms of medal totals. Looking at Japan's results in trades closely connected to manufacturing in which it has steadily competed (7 trades in 1962, 11-14 since then), Japan's medal rate (medals divided by trades in which it competes) is gradually declining.The type and number of trades actually engaged in change with the times, but except for its earliest competitions Japan has generally participated in 80 to 90 percent of the trades. Participation is declining along with the medal rate (see Figure 2).

9.5 Conditions in Japan

9.5.1 Contests held in Japan

A number of contests are held in Japan in addition to those described above. Table 8 shows some examples of contests held on a regular basis.

Chiba Institute of Technology's Whale Ecology Observation Satellite (WEOS), which received an award at the first Satellite Design Contest, is scheduled to be piggy-backed into orbit on ADEOS-II via the H-IIA. In the Birdman Contest, improved manufacturing and flight technologies led to a record human-powered propeller flight of 23, 688 km in 1998 and a record glider flight of 417 m in 2001.

9.5.2 Participation in international contests

The top countries in recent International Science Olympiads are China, Russia, the United States, South Korea, and Taiwan. In the Mathematical Olympiad, the only one it competes in, Japan is in the upper half of the second 10. In programming contests for university students, Japan finishes in the mid-teens, in contrast to the United States, Russia, Canada, and China, who have numerous universities finishing in the top 10. In the Skills Olympics, South Korea is overwhelmingly strong, and Japan is consistently third or fourth. Contests do not measure all scientific and technological abilities, and results also depend on contest-specific training, so the future scientific and technological level of a country cannot be obtained directly from contest results. Moreover,

Table 8: Examples of contests held in Japan

Type	Name	Competitors	Organizer	Overview	History
Mathematics	Mathematical Olympiad Hironaka Cup Japan Jr. High Mathematics Contest	Elementary. The Hironaka Cup is for jr. high.	Mathematical Olympiad Committee	Established at the suggestion of Kyoto University emeritus professor Heisuke Hironaka. Outstanding performers at the Mathematical Olympiad attend the World Youth Mathematics Conference in Hong Kong.	Since 1992; jr. high competition since 2000.
	Japan Mathematics Contest, Junior Mathematics Contest	High school. Junior contest is jr.high.	Japan Mathematics Contest Committee	Mathematics contest operated by the Japan Mathematics Contest Committee comprising Nagoya University and high school educators and chaired by Masayuki Ito.	Since 1990; junior contest since 1997; thesis prize since 2000.
Science	Natural Science Observation Contest	Elementary, jr. highstudents	Mainichi Shinbun, Natural Science Observation Research Society, others	Observation and record keeping of habitat and growth of animals and plants, minerals, astronomy, weather.	Since 1960.
	Science Grand Prix	Elementary 4-6 grade, jr. high, Kanto region, Yamanashi and Shizuoka Prefectures	Tokyo Electric Power Co.	Contest in basic science with summer vacation projects. All aspects of natural science (chemistry, physics, biology, geology, environment, etc.).	Since 1995.
	Japan Art and Science Contest	Elementary, jr. high, high school (natural .science for jr high and high school)	Obunsha Co.	14 fields in three sectors: information/science, art, literature. Information/science sector includes multimedia, human/social science research, natural science research.	Since 1957.
Programming	Japan High School and Vocational School Student Programming Contest	High school, vocational school 1-3 grade, vocational college	Informatization Month Promotion Council, Ministry of Economy, Trade and Industry, Japan Information Processing Development Association.	A major event during National Informatization Month. Comprises a programming sector and a content sector.	Since 1980.
	Japan High School and Vocational School Programming Contest	High school	High School and Vocational School Contact Committee.	Issue sector (sports and computers this year), free sector, competition sector.	Since 1990.
	JSPP Parallel Software Contest	Students in high school, vocational school, vocational college, university, graduate school. Open section is unlimited.	PSC2001 Executive Committee.	Contest on designated parallel computers (cutoff particles) and free sector. (JSPP comprises several information processing societies related to parallel processing. It holds several symposiums related to parallel processing each year.)	Since 1994.
Technology	Satellite Design Contest	High/vocational school, university, graduate school students	Japan Society for Mechanical Engineering, Japan Society for Aeronautical and Space Sciences, Institute of Electronics, Information and Communications Engineers, Institute of Space and Aeronautical Science, National Space Development Agency, SPSS, Japan Space Forum.	Contest for open mission concepts, ideas, and designs of small satellites by students. Design and concept divisions.	Since 1993.
	Japan Robot Sumo Tournament	High school and general	Fuji Soft ABC Inc. The National Association Principals of Technical Senior High School	All-Japan (general) and high school divisions. Autonomous and radio-controlled robots (20 cm wide, 20 cm deep, any height, 3 kg or less).	Since 1990; high school division since 1993.
	Japan Micromouse Conference Japan Student Micromouse Contest	Open. There is a jr.high robot race division. High school, vocational, university students	New Technology Foundation.	Proposed by the USA's IEEE (Institute of Electrical and electronics Engineers) in 1977 as a competition to explore the possibilities of microcomputers. In addition to Japan, competitions are held in Europe and Asia. The contest comprises timed races through mazes by "mice" (self-propelled small vehicles loaded with microcomputers and sensors). The 2001 contest included micromouse races, robot races, and microclipper races.	Since 1980; student competition since 1986.
	Dream Cup Suzuka Solar Car Race	Open.	Yomiuri Shimbun, Suzuka Circuit Land, Japan Automobile Federation (JAF).	Endurance races of 8 or 4 hours depending on battery type, and electric car races.	Since 1992.
	Birdman Contest	Open.	Yomiuri Broadcasting.	Flight contest made for television with homemade aircraft. Glider, human-powered propeller, and human-powered helicopter divisions.	Since 1977

Source: Contest websites.

there is no guarantee that those who do well in contests will even remain in those fields. Nevertheless, one can hardly say that Japan's current results are outstanding.

Contest participation can

— Build the skills of young people. (Contests can provide goals for young people and become appropriate stimuli to build their skills.)
— Provide experience on a wider stage. (Participation can inspire young people to set new goals after experiencing world-class competition, make them aware of the importance of language study, and inspire them to take on new challenges. Accomplishing a task can build great confidence.)
— Shine a spotlight on the world of science and technology. (When contests or those who excel in them are reported on in the media and praised, society becomes more aware of the world of science and technology, and that world itself is vitalized.)

Those things can result from contest participation. In Japan as well, there is movement not only to participate in existing contests, but also to propose new international competitions and give young people opportunities to take on such challenges. At the same time, however, some question the results, claiming that only a few students benefit so the overall level is not raised and widespread interest is not generated.

Reasons given for a lack of widespread participation include, first, the difficulty of finding participants. In Japan there is a strong sense that time spent on problems outside the standard high school curriculum is time taken away from study for entrance examinations. Because participation and prizes do not bring any benefit to scholastic plans, students, parents, and teachers are not very interested in them. In contrast, ISEF, for example, offers scholarships and can lead to recruitment by universities and opportunities for internships, so interest is high in the United States. The autobiographical novel Rocket Boys by a former NASA engineer tells how ISEF led the main character from dreaming about launching homemade rockets to actually fulfilling his dreams. In China, where results in Science Olympiads are connected to university admissions and scholarships, "Olympic fever" has grown to the point that there are now special tutoring schools that teach students how to succeed in Olympiads.

In the case of the World Skills Competition, doing away with in-house training schools is said to have weakened Japanese competitors. According to Kagaku Gijutsu Gakuen High School, which is connected to vocational training schools and offers high school diplomas, in 1970 and 1971 it had links to 41 corporate training schools, but by 2002 that number had shrunk to 5. With a higher percentage of young people going to college, it has become difficult to secure people of the right age for vocational training and participation in the Competition.

A second problem is lack of awareness. With the exception of competitions sponsored by media companies, contests are not in the public eye, and society's awareness of them in general is low. Therefore even when students are selected for international competitions, and even if they do well there, they are not reported on or publicly praised like athletes or performers, so participation and prizes are not exciting for young people.

A third problem is securing financial resources. Most contests have insufficient funding as well as too few university professors to provide volunteer leadership. In particular, hosting that costs a few hundred million yen are a major issue for would-be participants. Corporate support is difficult to find because of the recession, and public support is not currently forthcoming. Japan's ISEF leadership points out that corporations in the United States have a much stronger sense of an obligation to gave back to and contribute to society.

9.6 Conclusion

While Japan is not currently a top-class competitor in international contests, there are some circumstances that give hope for the future as various contests are held.

In the Japan Mathematical Olympiad, junior high school and elementary school students who are developing their talents from an early age can be found among the outstanding performers. At the 12th Olympiad in February 2002, the 20 outstanding competitors included three third-year junior high school students and one sixth-grade elementary school student. At the 11th Olympiad, the top 17 competitors included six junior high school students, three of whom won awards for finishing in the top 5. With 10 years having passed since Japan began participating, former competitors now in graduate school are able to provide coaching to current team competitors.

At ISEF, although the quality of Japanese projects is considered generally high, lack of presentation experience and language ability lead to difficulty in getting the attention of judges, which is a concern for Japanese participants.

At the Supercomputer Contest, teams that outperform university teams and teams that produce elegant albeit not generalizable solutions different from those developed by the testers can be seen after only one day of lectures. Those programs have subsequently been used in university courses. Despite the fact that it will be of no use on entrance examinations, some students have been excited by encountering supercomputers for the first time and taking on advanced problems to such an extent that they will sometimes stay up all night working on programs.

Regarding skills, society as a whole is reevaluating them, and the environment is becoming brighter. In some corporations, fully-skilled technicians at manufacturing sites are being considered and treated as experts. Efforts to appreciate and handle technicians more appropriately and to pass on their skills are being made, with systems for passing on skills to new generations and to give technicians the same job titles (department manager, section chief, etc.) as office workers being put in place. The advanced technical skills of small and medium companies and the difficulty of passing them on, as well as the problems skilled workers have finding reemployment are being reported in the mass media, and society is becoming more aware of them.

In 2003, Japan will host the Mathematical Olympiad and participate in the Chemistry Olympiad for the first time. For young people interested in science and technology, opportunities to take on new challenges will continue to expand. Holding and participating in science and technology contests bears watching as one index of science and technology.

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About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative organizations, with MEXT and other ministries under the general supervision of the Council for Science and Technology Policy, Cabinet Office (CSTP), to develop strategic science and technology policy.

NISTEP has established the Science and Technology Foresight Center (STFC) with the aim to strengthen survey functions about trends of important science and technology field. The mission is to provide timely and detailed information about the latest science and technology trends both in Japan and overseas, comprehensive analysis of these trends, and reliable predictions of future science and technology directions to policy makers.

Beneath the Director are five units, each of which conducts surveys of trends in their respective science and technology fields. STFC conducts surveys and analyses from a broad range of perspectives, including the future outlook for society.

The research results will form a basic reference database for MEXT, CSTP, and other ministries. STFC makes them widely available to private companies, organizations outside the administrative departments, mass media, etc. on NISTEP website.

The following are major activities: ....

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— STFC builds an information network linking about 3000 experts of various science and technology fields in the industrial, academic and government sectors. They are in the front line or have advanced knowledge in their fields.

— Through the network, STFC collects information in various science and technology fields via the Internet, analyzes trends both in Japan and overseas, identifies important R&D activities, and prospects the future directions. STFC also collects information on its own terms from vast resources.

— Collected information is regularly reported to MEXT and CSTP. Furthermore, STFC compiles the chief points of this information as topics for "Science and Technology Trends" (monthly report).

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— Targeting the vital subjects for science and technology progress, STFC analyzes its trends deeply, and helps administrative departments to set priority in policy formulating.

— STFC publishes the research results as feature articles for "Science Technology Trends" (monthly report).

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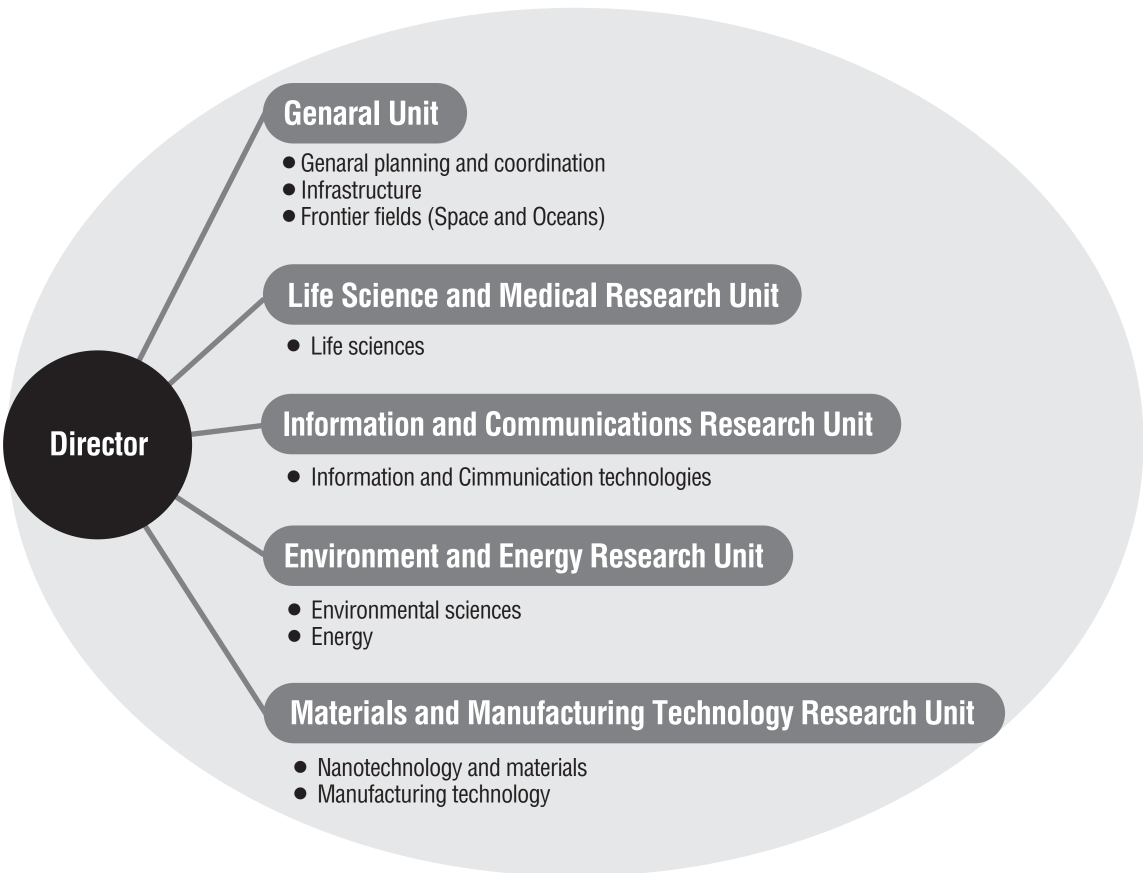
— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



＊Units comprise permanent staff and visiting reseachers (non-permanent staff)
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